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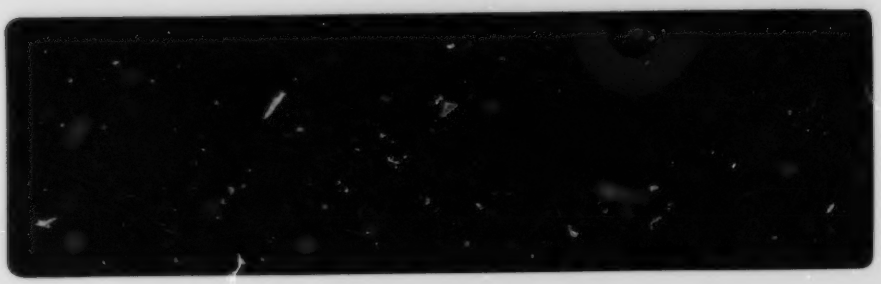

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DEVELOPMENT OF A PROCEDURE FOR CALCULATING TOTAL WINDOW U-VALUE AND SHGC

PREPARED FOR:

Efficiency and Alternative Energy Technology Branch
Energy, Mines and Resources Canada
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PREAMBLE

This work was carried out under contract for Energy, Mines and Resources Canada (EMR) as part of the CANMET High-Performance-Window Project. This project includes support for the development of window performance standards and labelling procedures.

Window thermal performance standards, under development by the Canadian Standard Association (CSA), include procedures for calculating total window performance from component simulation and tabulated values for a wide range of window types. Procedures are based on two EMR computer programs: VISION, supported by the University of Waterloo, provides thermal analysis of simulated glazing systems, and FRAME, developed and supported by Enermodal Engineering Ltd, is a graphical design tool for thermal analysis of window frames.

This report presents ongoing work for the CSA Subcommittee on Energy Evaluation of Windows and has been useful as input to the energy performance standard.

EMR, Ottawa
January 1991

PRÉAMBULE

Cette étude a été conduite sous contrat avec Énergie, mines et ressources Canada (EMR) dans le cadre du prcjet "Fenêtres performantes" de CANMET. La participation à l'établissement de normes et labels concernant l'efficacité thermique des fenêtres fait partie des objectifs de ce projet.

Des normes d'efficacité énergétique des fenêtres, qui sont actuellement établies par l'Association canadienne de normalisation (Acnor), offrent l'option de calculer l'efficacité de la fenêtre complète à partir d'une simulation des composantes de la fenêtre et de valeurs tabulées pour un large éventail de types de fenêtres. La méthode repose sur deux programmes d'ordinateur de EMR: VISION, de l'Université de Waterloo, qui permet l'étude thermique du vitrage simulé, et FRAME, de Enermodal Engineering Ltée, qui est un outil de conception graphique pour l'analyse thermique des cadres de fenêtres.

Ce rapport reflète les travaux en cours du sous-comité Acnor d'évaluation énergétique des fenêtres et joue un rôle important dans l'établissement d'une norme sur l'efficacité energétique des fenêtres.

EMR, Ottawa
Janvier 1991

EXECUTIVE SUMMARY

This report develops and documents a procedure for determining total window U-value and Solar Heat Gain Coefficient (SHGC). The procedure is based on determining the component values (centre-glass, edge-glass, and frame) of these quantities. A manual calculation procedure for total-window U-value and SHGC, based on the equations and tabular data given in this report, is described. Centre-of-glass U-values and SHGC for a wide range of glazing systems are tabulated. Frame U-values are tabulated for a wide range of frame types. Equations are given for edge-of-glass U-values and frame SHGC.

This report examines the accuracy of the FRAME and VISION computer programs in predicting window energy performance. The average difference between VISION/FRAME-simulated and NRC-tested total-window U-values was 2.4% for the 13 windows studied. The FRAME program predictions for frame and edge heat loss are all within the uncertainty margins of the NRC test results. Therefore, the FRAME program appears to provide reasonable estimates of frame and edge heat loss. The FRAME program was used to generate 79 values of frame U-values covering the range of typical residential window products.

This report also examines the effect of outdoor temperature, solar radiation level, outside film coefficient and angle of incidence on the SHGC. The variation in centre-of-glass SHGC as a function of the outdoor temperature, solar radiation level and outside film coefficient was less than one percent over a wide range in each parameter for a typical residential window. SHGC was found to be a function of incidence angle, but a simple equation can be used to calculate an off-normal incidence factor, where required, regardless of glazing type.

The effect of frame and edge-of-glass heat transfer on the total-window SHGC was studied, and has little effect on the SHGC for windows with wooden frames. The effect of the frame and edge-of-glass on the SHGC for windows with aluminum or thermally-broken aluminum frames is less than five percent. A simple equation can be used to calculate frame SHGC as a function of frame U-value.

RÉSUMÉ DE DIRECTION

Ce rapport établit une méthode de calcul de la valeur U et du coefficient de gain solaire relatifs aux fenêtres. Selon cette méthode, le calcul de ces deux paramètres repose sur l'évaluation de la valeur de leurs composantes, comprenant le centre du vitrage, la bordure du vitrage et le cadre. Ce rapport décrit une méthode de calcul à la main, et les équations et tables de données utilisées y sont présentées en détail. Les tables de données fournissent la valeur U et le coefficient de gain solaire relatifs au centre-du-vitrage pour un large éventail de vitrages, ainsi que la valeur U d'un grand nombre de cadres de fenêtres de types variés. La valeur U du bord du vitrage ainsi que le coefficient de gain solaire des cadres sont par contre calculés.

On examine dans ce rapport la précision des valeurs de l'efficacité énergétique des fenêtres telles que prédites par FRAME et VISION. La comparaison des résultats obtenus par mesure expérimentale au CNRC avec ceux simulés sur ordinateur par VISION/FRAME, pour un échantillon de treize fenêtres, montre une différence moyenne de l'efficacité de 2.4 %. L'analyse montre que les pertes de chaleur au niveau du cadre et en bordure du vitrage, calculées par FRAME, sont comparables à celle mesurées au CNRC, compte-tenu de l'incertitude expérimentale. Il semble donc raisonnable d'utiliser FRAME pour évaluer ces pertes de chaleur. On a utilisé FRAME pour établir une table de valeurs U pour le cadre de 79 fenêtres, couvrant ainsi un éventail de fenêtres typiquement utilisées en construction résidentielle.

Ce rapport se penche aussi sur l'impact sur le coefficient de gain solaire de facteurs tels que la température extérieure, le niveau d'ensoleillement, le coefficient de transfert de chaleur à la surface de la fenêtre et l'angle d'incidence solaire. On a montré que la variation du coefficient de gain solaire du centre du vitrage en fonction des trois premiers paramètres précédents ne se montait pas à un pour cent, et ceci pour une variation importante de ces paramètres. On a trouvé que le coefficient de gain solaire dépend de l'angle d'incidence solaire. En outre, l'utilisation d'une simple équation de calcul du facteur d'incidence sous angle non-droit permet, lorsque nécessaire, d'obtenir le coefficient de gain solaire.

On a étudié l'influence des pertes de chaleur par le cadre et la bordure du vitrage sur le coefficient de gain solaire de la fenêtre complète. La variation de ce coefficient est faible dans le cas des fenêtres à cadre en bois, et de moins de cinq pour cent dans le cas des fenêtres à cadre d'aluminium isolé ou non. Le calcul du coefficient de gain solaire du cadre peut être effectué de manière simple, en fonction de la valeur U du cadre.

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1. INTRODUCTION

Windows have a major impact on the energy consumption of buildings. A heat balance on the window gives the equation

$$Q_{win} = SHGC * I_T - U_w (T_{ig} - T_a)$$

where SHGC is the window Solar Heat Gain Coefficient and includes transmitted solar radiation plus solar radiation that is absorbed by the glazings and is conducted/radiated into the building

I_T is the solar radiation incident on the window

U_w is the window U-value

T_{ig} is the indoor building air temperature

T_a is the ambient outdoor air temperature

Two window properties--U-value and solar heat gain coefficient (SHGC)--are needed to evaluate this impact. The 1989 ASHRAE Handbook of Fundamentals is the most frequently used source for window properties. Although this source has a rather complete list of centre-glazing U-values, the edge-of-glazing and frame U-values are available for only two spacers and four frame types. This information is clearly inadequate to represent the range of commercial window products. A more complete treatment of edge-of-glass U-values is contained in Enermodal [1987] and Arasteh [1989]. A complete table of frame U-values does not yet exist. The information available for SHGC is even more incomplete: the ASHRAE Handbook lists only a few SHGC's for the most common glass types, and has no information on overall or total-window SHGC.

As an alternative to the ASHRAE handbook, computer programs can be used to determine total window component U-values and SHGC. These programs include FRAME [Enermodal, 1989], VISION [University of Waterloo, 1989] and WINDOW [LBL, 1988]. These programs are to be used in window labelling programs being developed by the Canadian Standards Association and the U.S.-based National Fenestration Rating Council. These programs, although useful in determining an individual manufacturer's window properties, are time-consuming and require a trained operator. Consulting engineers, architects and policy makers need a simple (manual) technique for determining total-window thermal properties.

This report summarizes the development of a manual method for determining window properties and presents examples of how it is to be used. The method uses tables and simple equations of window component U-values and SHGC's. The total-window property value is simply the area-weighted average of the component values. The centre-glazing U-values and SHGC's were determined using the VISION computer program. The FRAME program was used to determine edge-of-glass and frame U-values and SHGC's. The accuracy of the VISION and FRAME programs in predicting total-window U-value is also examined in this report.

2. ACCURACY OF THE COMPUTER PROGRAMS

2.1 Methodology

To have confidence in the tables and figures presented in this report, the accuracy of the computer programs used to generate this information must be verified. One of the best methods of evaluating the accuracy of a computer program is to compare simulation results to precise experimental results. The guarded heater-plate apparatus (GHPA) at the University of Waterloo is one of the best glazing-unit test instruments for measuring centre-of-glass heat transfer. The quoted accuracy of the GHPA measurements is three percent [Wright, 1990]. The guarded hot box at the National Research Council of Canada (NRC) is one of the best window test facilities in the world for measuring total-window heat transfer. The published accuracy of their tests is six percent [Elmahdy and Bowen, 1988]. Unfortunately, there is not an accurate test facility with a recognized test procedure for determining SHGC. (Note: Queen's University is developing a procedure for experimental determination of SHGC [Dubrous and Harrison, 1989]. When the accuracy of this facility has been determined, it can be compared to calculated methods.)

Numerous studies have been conducted to compare VISION simulations to measured results from the GHPA [Wright and Sullivan, 1987; Baker et. al., 1989]. The simulations and measured results compared favourably (within five percent in most cases), and as such the accuracy of the VISION program will not be discussed further.

The NRC has tested 13 windows for which the results are not confidential and the window constructions are documented. FRAME simulations have been performed on these 13 windows, seven of which (numbered 1 through 7) were part of a joint Canada/US research project into window performance. The frame cross-sections are shown in Appendix A and details of the simulations are documented in Elmahdy [1990]. Three windows were simulated as a part of a Queen's University study on window performance [Dubrous and Harrison, 1989] and the remaining three windows were simulated in support of the Flair Homes study of high-performance windows [Ortech, 1989].

The simulations for all the windows, except the Queen's windows, were performed "blind"--that is, the results of the NRC tests were not disclosed until the simulated results were released. The simulation results for the six windows not previously reported are given in Sections 2.2 and 2.3.

2.2 Simulated Performance of the Queen's University Windows

The Solar Calorimetry Lab of Queen's University had three windows tested at NRC as part of the evaluation of their method for testing window thermal performance. The thermal performance of these windows had been simulated with an earlier version (1.2) of the FRAME program. The maximum number of rectangles used to draw the window frame was limited to 40, requiring the frame cross-section to be greatly simplified for simulation. Some misunderstanding in the application of the program led to some slight discrepancies and as such their results would not be indicative of the program accuracy. It was decided that the windows should be re-simulated.

The FRAME representation of the three window cross-sections are shown in Figures 1, 2 and 3. The physical dimensions of the windows were obtained from the respective manufacturers' drawings. The material property values used (i.e., thermal conductivities and optical values) were the default values in the two computer programs. The windows are

Window #8:

- double-glazed air-filled cavity
- dual-seal aluminum spacer
- aluminum casement frame with 10 mm thermal break

Window #9:

- double-glazed air-filled cavity
- dual-seal aluminum spacer
- solid wood casement frame (with aluminum cladding)

Window #10:

- triple-glazed, air-filled cavity with one low-e coating
- dual-seal aluminum spacer
- solid wood casement frame (with aluminum cladding)

The emissivity of the low-e coating was taken to be 0.09, as recommended by the manufacturer.

FIGURE 1: FRAME REPRESENTATION OF WINDOW #8

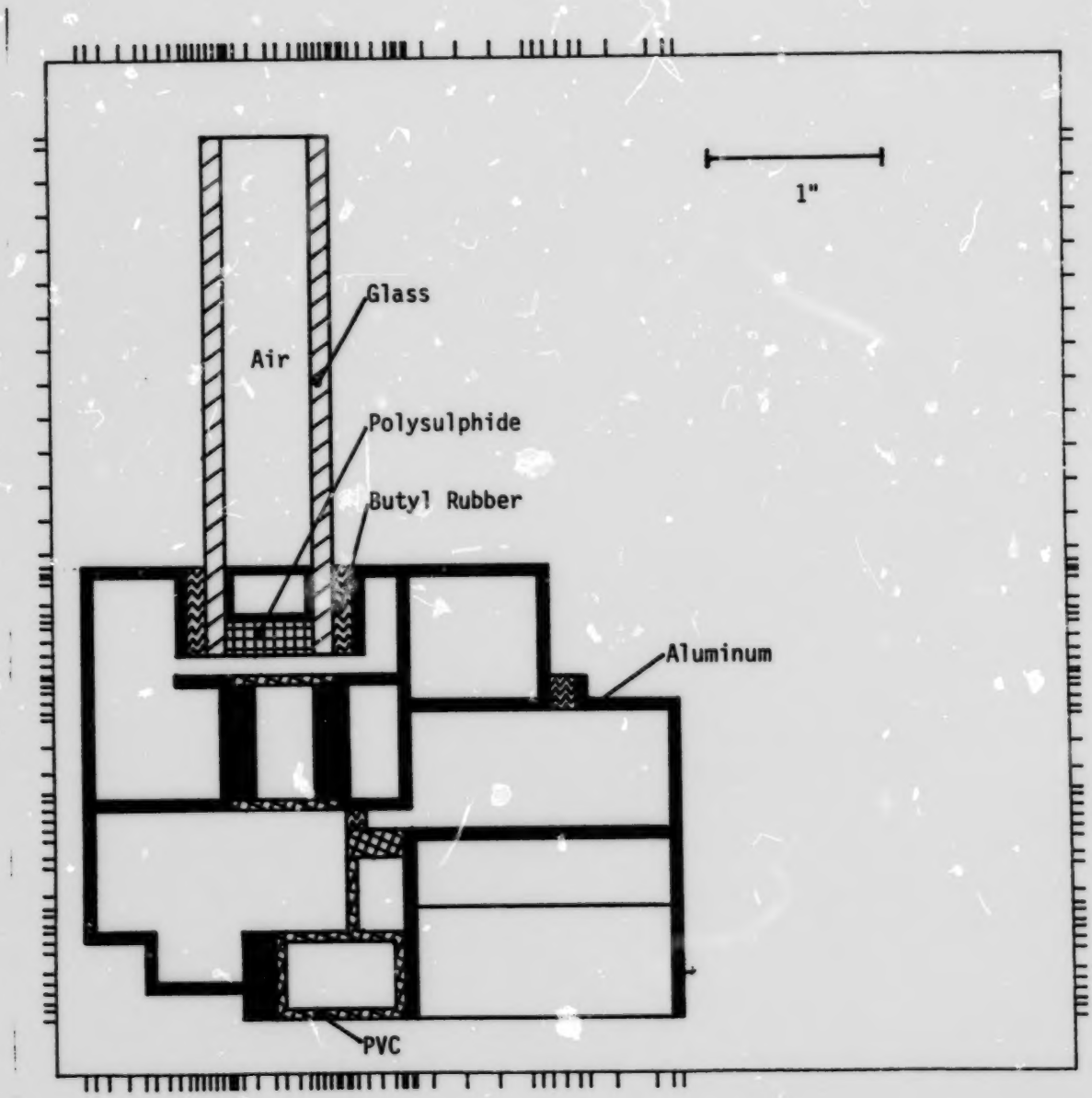


FIGURE 2: FRAME REPRESENTATION OF WINDOW #9

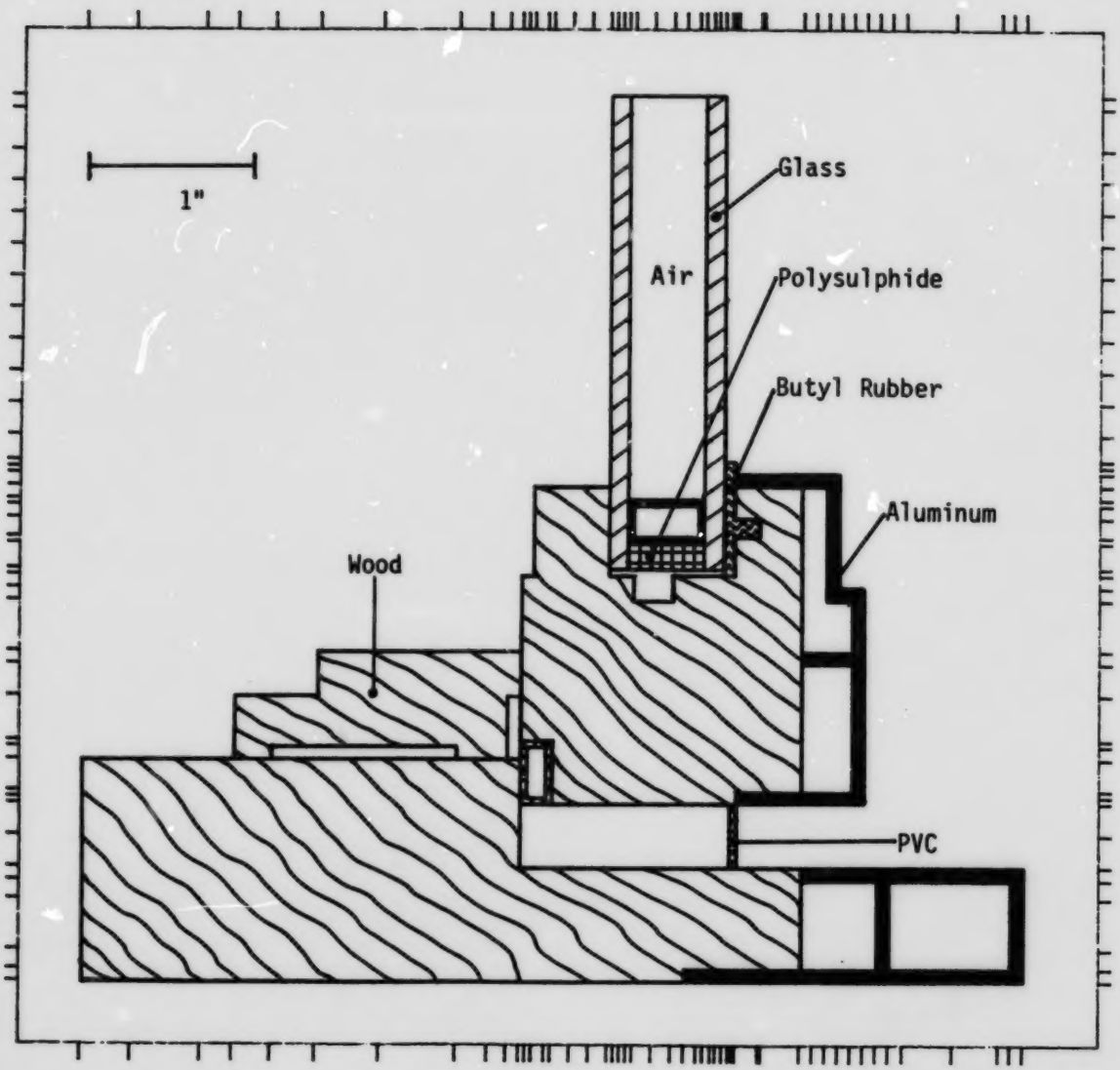
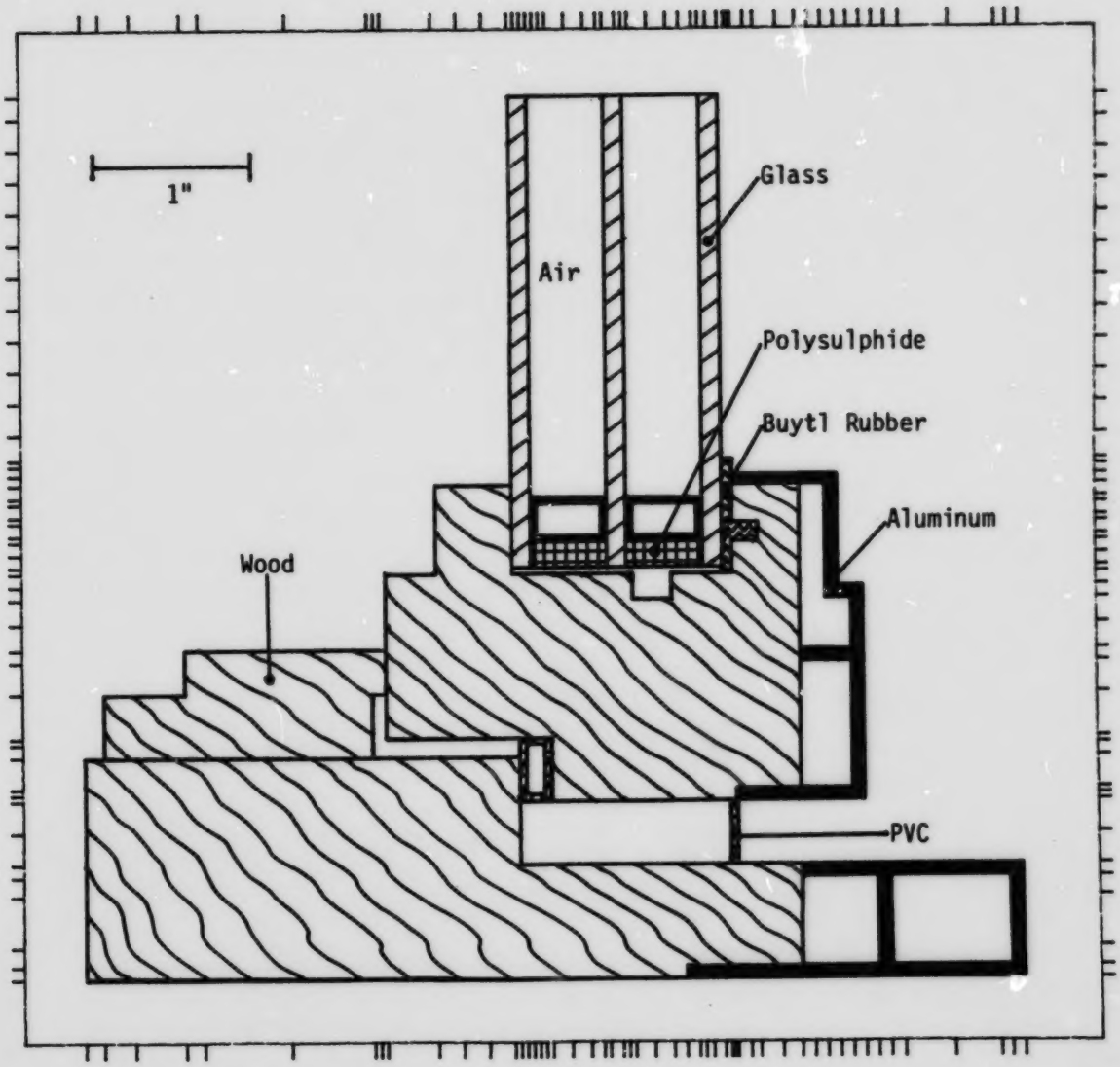


FIGURE 3: FRAME REPRESENTATION OF WINDOW #10



The results of the simulations are summarized in Table 1. The centre-glazing U-values were determined using the VISION program. The frame and edge-of-glazing U-values were determined using the FRAME program. The simulations were performed under the standard winter design conditions, namely:

Exterior:	T = -18 °C	Interior :	T = 21 °C
	h = 34.5 W/(m²•C)		h = 7.5 W/(m²•C)

The window U-values were adjusted for the NRC test film coefficients of 30 W/(m²•C) outside and 8.3 W/(m²•C) inside, to permit comparison of the simulation results to NRC test results.

2.3 Simulated Performance of Three High-Performance Windows

The thermal performance of three windows designed to have high thermal resistance were simulated using the FRAME computer program for frame and edge-of-glass heat transfer and VISION for centre-glazing heat transfer. The FRAME representation of the three window cross-sections are shown in Figures 4, 5, and 6. The physical dimensions of the windows were obtained from the respective manufacturers. The material property values used (i.e., thermal conductivities and optical values) were the default values contained in the two computer programs. Our understanding of the window constructions is described below. (Note: An investigation had to be undertaken to resolve some conflicting information on the spacer materials and presence of low-e coatings and argon gas fills contained in the various test reports and manufacturers' literature.)

Window #11:

- quadruple-glazed, with the inner two panes being Heat Mirror 88, air-filled cavities
- all three spacers are mild steel
- solid wood frame (no cladding)

Window #12:

- triple-glazed, with two low-e coatings and two argon gas fills
- both spacers are Swiggle Strip
- solid wood frame (no cladding)

Table 1: Queen's University Window Simulation Results

Window	8	9	10
Description	Double-glazed TB Alum.	Double-glazed Wood	Triple-glazed Wood
U-centre [W/(m²*C)]	2.75	2.87	1.34
U-edge [W/(m²*C)]	3.24	3.33	2.16
U-frame[W/(m²*C)]	4.68	2.40	2.09
U-total [W/(m²*C)]	3.32	2.85	1.74
% Glazing	84.5	85.3	75.8

U-values include NRC standard film coefficients.

FIGURE 4: FRAME REPRESENTATION OF WINDOW #11

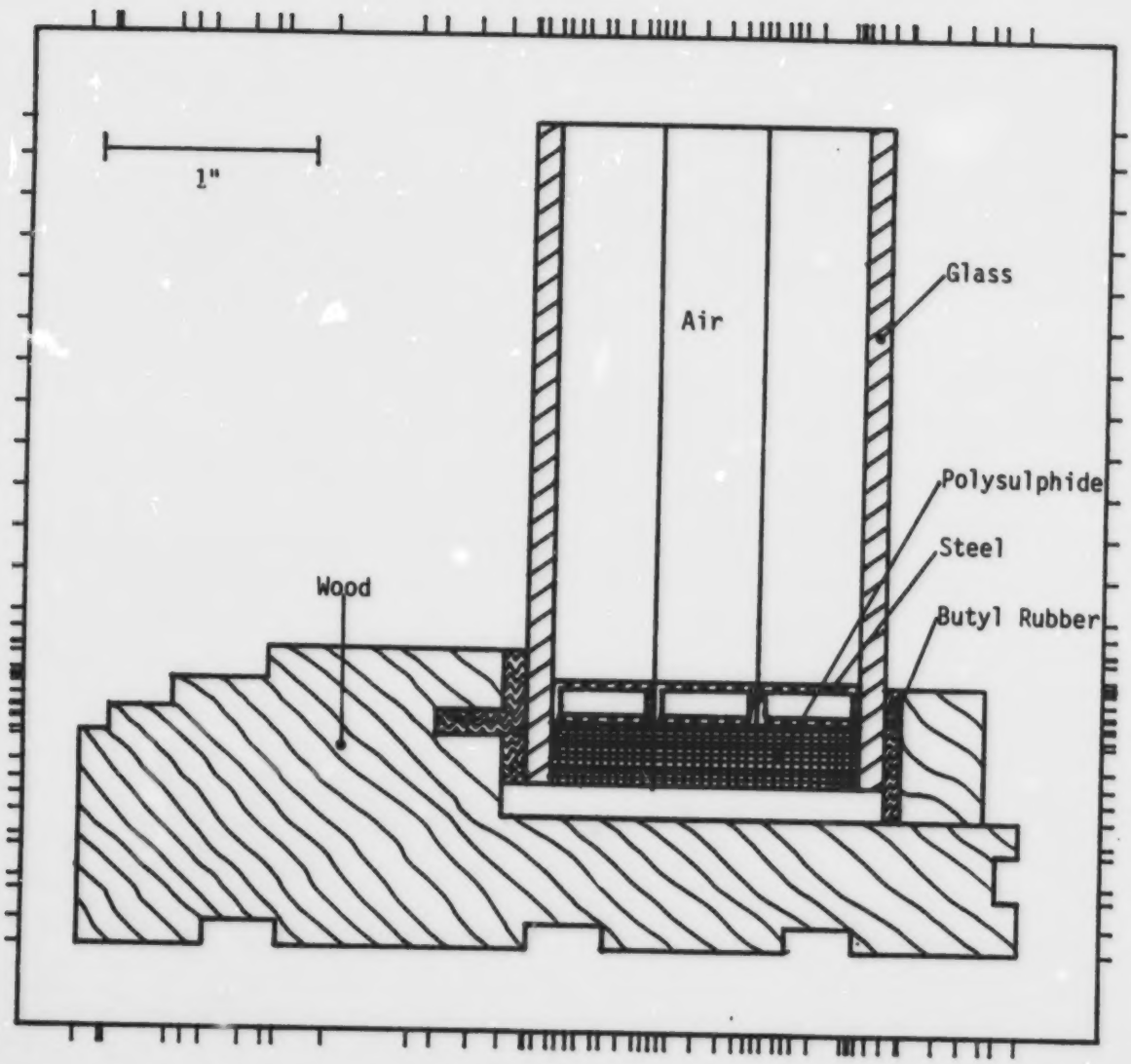


FIGURE 5: FRAME REPRESENTATION OF WINDOW #12

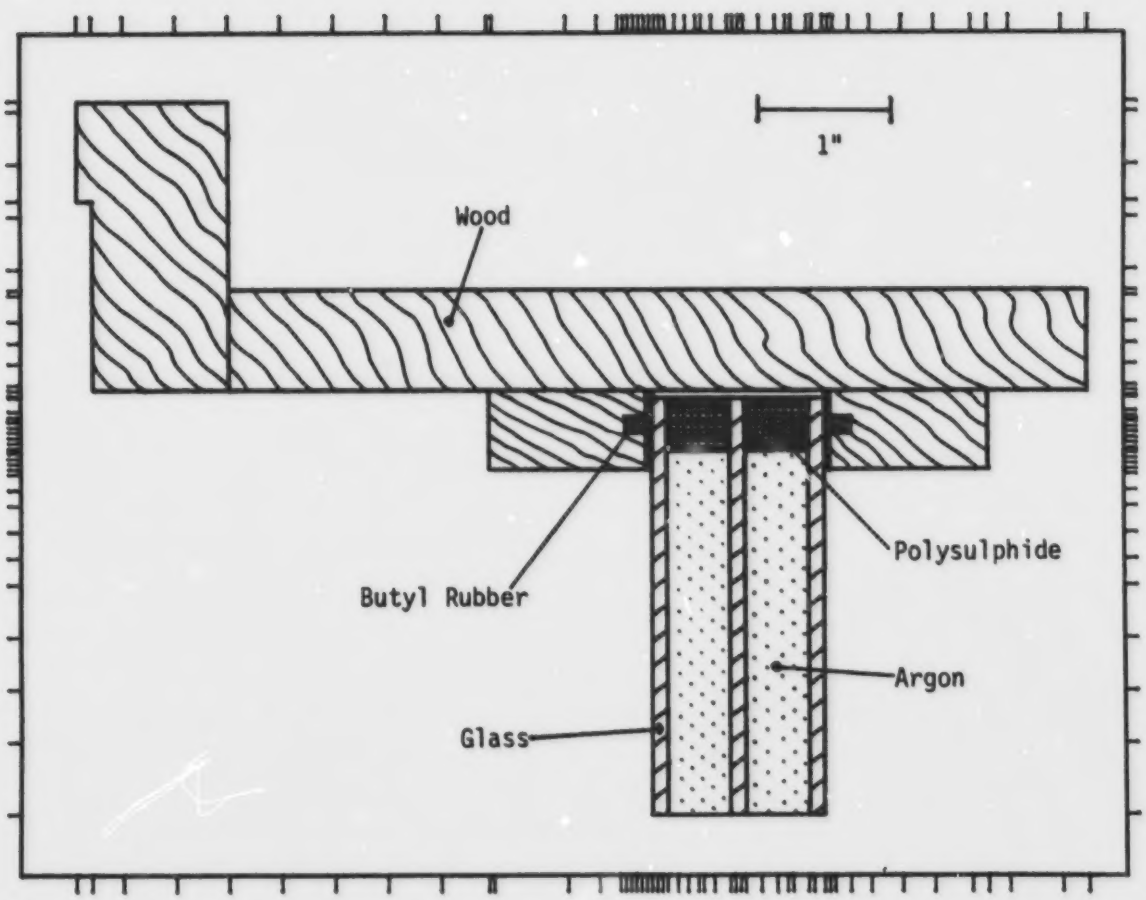
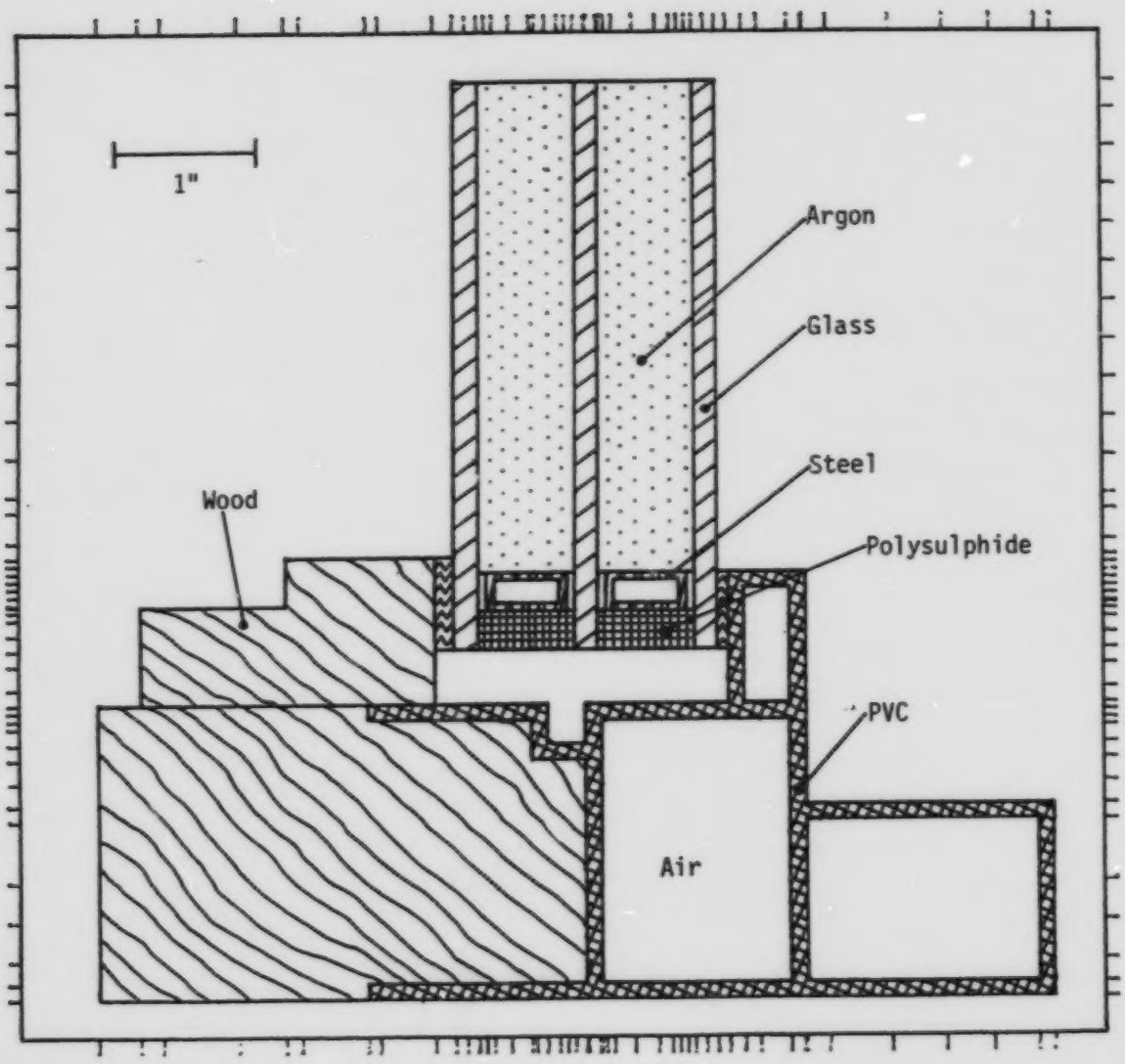


FIGURE 6: FRAME REPRESENTATION OF WINDOW #13



Window #13:

- triple-glazed, with two low-e coatings and two argon gas fills
- both spacers are dual-seal mild steel
- PVC exterior and wood interior frame

The emissivities of the low-e coatings were taken to be 0.09, as recommended by the manufacturers.

The results of the simulations are summarized in Table 2. The simulations were performed as described in Section 2.2. The centre-glazing SHGC's were simulated using the VISION program. In the analysis of these windows, frame and edge-of-glass effects on window shading coefficient were assumed to be small and were ignored.

2.4 Comparison of Simulated and Tested Window Performance

Table 3 compares the NRC-tested and FRAME/VISION-simulated window U-values. The largest difference is 5.9%, and the average difference is 2.4%. Given that the accuracy of the NRC test facility is 6%, we conclude that the accuracy of computer simulation of the total window is at least as good as that of NRC testing for these 13 windows. For this study, however, it is the accuracy of the FRAME program in predicting frame and edge-of-glazing heat transfer that is of interest. (The frame and edge-of-glazing heat loss are treated together, in this analysis, because both are predicted by the FRAME program.)

The test value of the frame and edge U-value can be backed out from the NRC tests using the VISION prediction for centre-glazing U-value:

$$U_{fe} = (U_t*A_t - U_{cg}*A_{cg})/A_{fe} \qquad (1)$$

where the subscripts fe, t and cg refer to the frame-and-edge, total and centre-glazing values

The uncertainty associated with this procedure can be calculated using standard statistical analysis. The error bound is

$$E_{fe} = \{ (E_t/[1-U_{cg}*A_{cg}/(U_t*A_t)])^2 + (E_{cg}/[U_t*A_t/(U_{cg}*A_{cg})-1])^2 \}^{1/2} \qquad (2)$$

where E is the error or uncertainty associated with each value

Table 2: High-Performance Window Simulation Results

Window	11	12	13
Description	Quad-Glazed Wood	Triple-Glazed Wood	Triple-Glazed Wood/PVC
U-centre [W/(m²*C)]	0.88	0.83	0.81
U-edge [W/(m²*C)]	1.85	1.20	1.52
U-frame [W/(m²*C)]	2.77	1.76	1.82
U-total [W/(m²*C)]	1.41	1.06	1.22
% Glazing	84.5	85.3	75.8
Solar Transmission	34.0	28.3	25.2
SHGC	0.43	0.42	0.37

U-values include NRC standard film coefficients.

SHGC and Solar Transmission are based on total window area

Table 3. Predicted and Tested Window U-values in W/(m²*C)

	Window Frame	Glazing	NRC Test	Predicted	% Diff. of Predicted from Test
1	T-B Alum. - Fixed	Double	3.55	3.37	-5.0
2	Wood - Casement	Double	2.70	2.80	3.7
3	T-B Alum. - Fixed	Double	3.51	3.43	-2.3
4	Aluminum - Fixed	Double	3.75	3.53	-5.9
5	Aluminum - Fixed	Single	6.85	6.61	-3.5
6	T-B Alum. - Fixed	Double-Low E	3.12	3.10	-0.6
7	Wood - Casement	Triple-Low-E	1.45	1.44	-0.7
8	T-B Alum. - Case.	Double	3.33	3.32	-0.3
9	Wood - Casement	Double	2.89	2.85	-1.4
10	Wood - Casement	Triple-Low-E	1.76	1.74	-1.1
11	Wood - Fixed	Triple-Low-E	1.10	1.06	-3.5
12	PVC/Wood Fixed	Triple-Low-E	1.22	1.22	-0.3
13	Wood - Fixed	Double+2 HM	1.37	1.41	3.0
			Average of Absolute Values		2.4

As discussed previously, the uncertainty in the total window and centre-glazing U-values are 6% and 3%, respectively.

Figure 7 and Table 4 show the FRAME predicted and "test" values of the frame/edge U-values. The uncertainty in the frame test result ranges between 9 and 17%. All of the FRAME program predictions are within the uncertainty bounds of the NRC results.

FIGURE 7: **Simulated & Tested Frame/Edge U-Values**

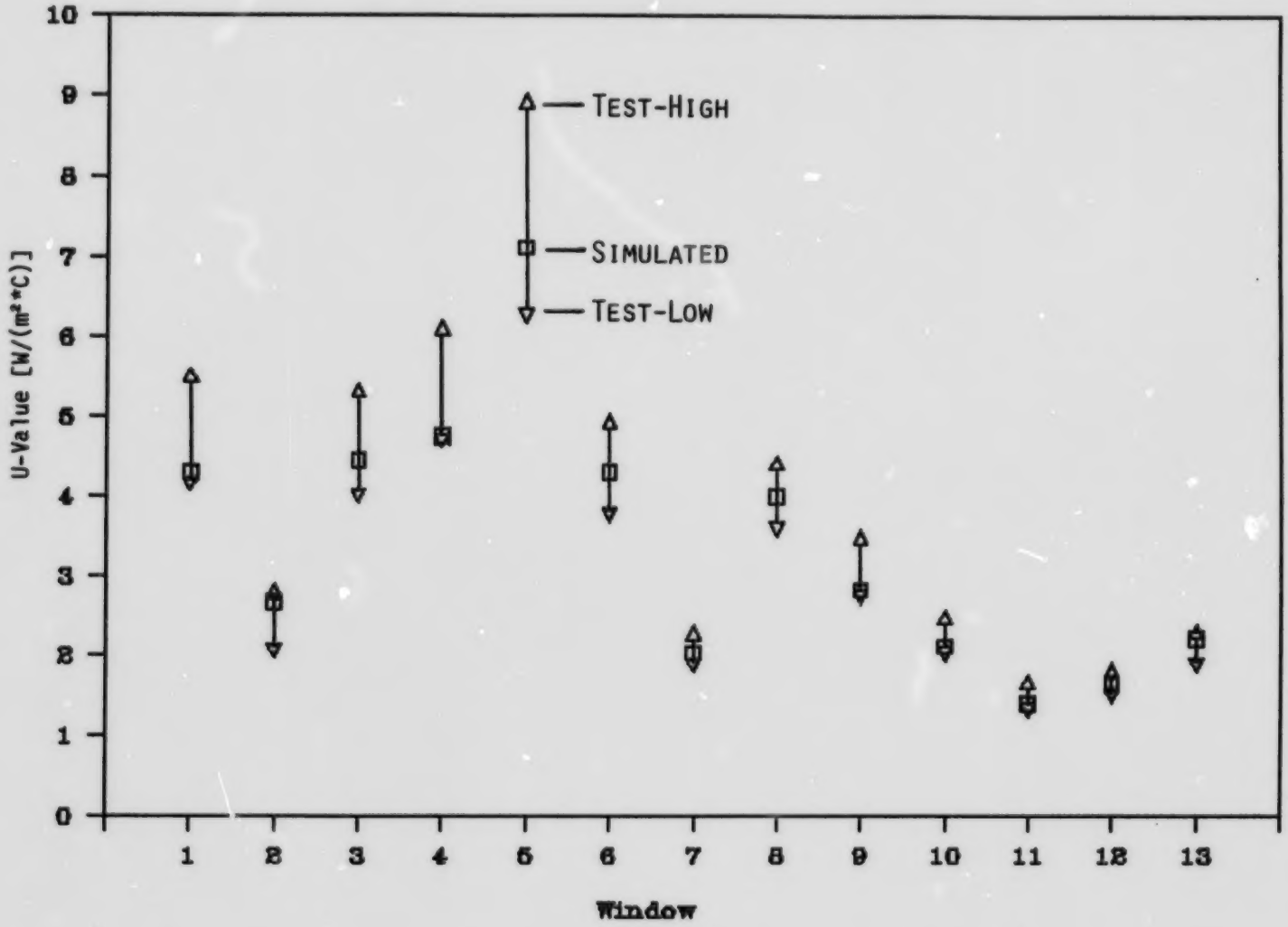


Table 4. Tested and Predicted Frame/Edge U-Values [W/(m²*C)]

	Window Frame	Glazing	Test[1] Result	Uncertainty[2] %	Uncertainty Range High	Uncertainty Range Low	Predicted Result
1	T-B Alum. - Fixed	Double	4.82	13.9	5.50	4.15	4.29
2	Wood - Casement	Double	2.43	14.9	2.80	2.07	2.67
3	T-B Alum. - Fixed	Double	4.66	14.3	5.33	3.99	4.43
4	Aluminum - Fixed	Double	5.40	13.3	6.11	4.68	4.74
5	Aluminum - Fixed	Single	7.60	17.5	8.93	6.27	7.12
6	T-B Alum. - Fixed	Double-Low E	4.33	13.6	4.92	3.74	4.29
7	Wood - Casement	Triple-Low-E	2.08	9.4	2.27	1.88	2.04
8	T-B Alum. - Case.	Double	3.98	10.5	4.40	3.56	3.98
9	Wood - Casement	Double	3.09	12.0	3.46	2.71	2.81
10	Wood - Casement	Triple-Low-E	2.25	9.8	2.47	2.03	2.12
11	Wood - Fixed	Triple-Low-E	1.51	11.2	1.68	1.34	1.41
12	PVC/Wood Fixed	Triple-Low-E	1.66	9.2	1.82	1.51	1.67
13	Wood - Fixed	Double+2 HM	2.09	9.8	2.29	1.88	2.20

[1] Calculated from Equation 1

[2] Calculated from Equation 2

3. DETERMINATION OF TOTAL WINDOW U-VALUE

3.1 Methodology

According to the 1989 ASHRAE Handbook of Fundamentals, the total window U-value is the area-weighted mean of the centre-of-glass, edge-of-glass, and frame U-values. The VISION program can be used to calculate the centre-of-glass U-value and the FRAME program can be used to calculate the edge-of-glass and frame U-values.

The standard practice for calculating window component U-values is to normalize the component heat loss based on the projected area. The total window U-value is calculated by area-weighting the component values, based on their projected area. This is clearly the proper way to handle centre-of-glass and edge-of-glass, but may not be the best way to normalize the frame heat loss. Normalizing frame heat loss according to projected area, surface area, and perimeter is examined in Section 3.4.

The VISION program was used to calculate centre-of-glass U-values for various glazing system configurations and the results are included in Section 3.2. The edge-of-glass U-value has been correlated as a function of the spacer type and the centre-of-glass U-value, the correlation is included in Section 3.3. The FRAME program was used to model a number of commercially available windows and the results are discussed in Section 3.4.

3.2 Centre-of-Glazing U-Values

The VISION program was used to calculate centre-of- glass U-values for a wide range of glazing system configurations. The glazing systems modelled included single-, double-, and triple-glazing, and double-glazed units with one or two Heat Mirror films. Three pane spacings (i.e., the distance between each set of glazings) were analysed: 6 mm, 9 mm, and 13 mm. The fill gases used were either air or argon. The three low-emissivity coatings simulated were 0.09, 0.20, and 0.35. It was assumed that each low-emissivity coating faced a stagnant gas cavity (i.e., either surface 2 or 3 in a double-glazed window). The two Heat Mirror films simulated were Heat Mirror™ 66 and Heat Mirror™ 88. The centre-of-glass U-values are tabulated in Table 5.

Table 5. Centre-of-Glass U-Values as Calculated by VISION

GLAZING SYSTEM	U-VALUE [W/(m²·°C)]
Single, Glass	5.74
Double, Glass	
6 mm air filled	3.24
9 mm air filled	2.95
13 mm air filled	2.82
6 mm argon filled	2.98
9 mm argon filled	2.73
13 mm argon filled	2.65
Double, Glass, e = 0.09 on one surface	
6 mm air filled	2.53
9 mm air filled	2.04
13 mm air filled	1.87
6 mm argon filled	2.05
9 mm argon filled	1.84
13 mm argon filled	1.58
Double, Glass, e = 0.20 on one surface	
6 mm air filled	2.87
9 mm air filled	2.23
13 mm air filled	2.07
6 mm argon filled	2.24
9 mm argon filled	1.87
13 mm argon filled	1.79
Double, Glass, e = 0.35 on one surface	
6 mm air filled	2.84
9 mm air filled	2.45
13 mm air filled	2.29
6 mm argon filled	2.46
9 mm argon filled	2.13
13 mm argon filled	2.05
Triple Glass	
6 mm air filled	2.26
9 mm air filled	1.99
13 mm air filled	1.82
6 mm argon filled	2.00
9 mm argon filled	1.79
13 mm argon filled	1.68
Triple Glass, e = 0.09 on one surface	
6 mm air filled	1.87
9 mm air filled	1.51
13 mm air filled	1.29
6 mm argon filled	1.52
9 mm argon filled	1.23
13 mm argon filled	1.09
Triple Glass, e = 0.20 on one surface	
6 mm air filled	1.98
9 mm air filled	1.62
13 mm air filled	1.41
6 mm argon filled	1.63
9 mm argon filled	1.38
13 mm argon filled	1.23
Triple Glass, e = 0.35 on one surface	
6 mm air filled	2.05
9 mm air filled	1.74
13 mm air filled	1.54
6 mm argon filled	1.75
9 mm argon filled	1.50
13 mm argon filled	1.37

GLAZING SYSTEM	U-VALUE [W/(m²·°C)]
Triple Glass, e = 0.09 on two surfaces	
6 mm air filled	1.62
9 mm air filled	1.23
13 mm air filled	1.00
6 mm argon filled	1.24
9 mm argon filled	0.94
13 mm argon filled	0.79
Triple Glass, e = 0.20 on two surfaces	
6 mm air filled	1.74
9 mm air filled	1.38
13 mm air filled	1.16
6 mm argon filled	1.39
9 mm argon filled	1.11
13 mm argon filled	0.96
Triple Glass, e = 0.35 on two surfaces	
6 mm air filled	1.89
9 mm air filled	1.55
13 mm air filled	1.35
6 mm argon filled	1.56
9 mm argon filled	1.30
13 mm argon filled	1.17
Double Glass, one Heat Mirror™ 66 film	
6 mm air filled	1.80
9 mm air filled	1.43
13 mm air filled	1.21
6 mm argon filled	1.44
9 mm argon filled	1.14
13 mm argon filled	1.01
Double Glass, one Heat Mirror™ 88 film	
6 mm air filled	1.86
9 mm air filled	1.51
13 mm air filled	1.29
6 mm argon filled	1.52
9 mm argon filled	1.24
13 mm argon filled	1.10
Double Glass, two Heat Mirror™ 66 films	
6 mm air filled	1.40
9 mm air filled	1.11
13 mm air filled	0.92
6 mm argon filled	1.12
9 mm argon filled	0.88
13 mm argon filled	0.76
Double Glass, two Heat Mirror™ 88 films	
6 mm air filled	1.42
9 mm air filled	1.14
13 mm air filled	0.95
6 mm argon filled	1.15
9 mm argon filled	0.92
13 mm argon filled	0.80

3.3 Edge-of-Glass U-values

Edge-of-glass heat transfer is two-dimensional and requires detailed modelling for accurate determination. Based on detailed two-dimensional modelling, Arasteh [1989] developed a simple correlation to calculate edge-of-glass U-value as a function of spacer type and centre-of-glass U-value. The correlation is as follows:

$$U_{eg} = A + B * U_{cg} + C * U_{cg}^2 \quad (3)$$

where A, B, and C are correlation constants.

The correlation constants for metal, insulating (including wood), fused glass spacers, and a combination of insulating and metal spacers are included in Table 6. The correlation constants for the combination of metal and insulated spacers were derived from previous FRAME simulations which showed that 85% of the benefit of insulated spacers in triple-glazing is attributable to the first insulated spacer. The equation is displayed graphically in Figure 8.

3.4 Frame U-Values

3.4.1 Background

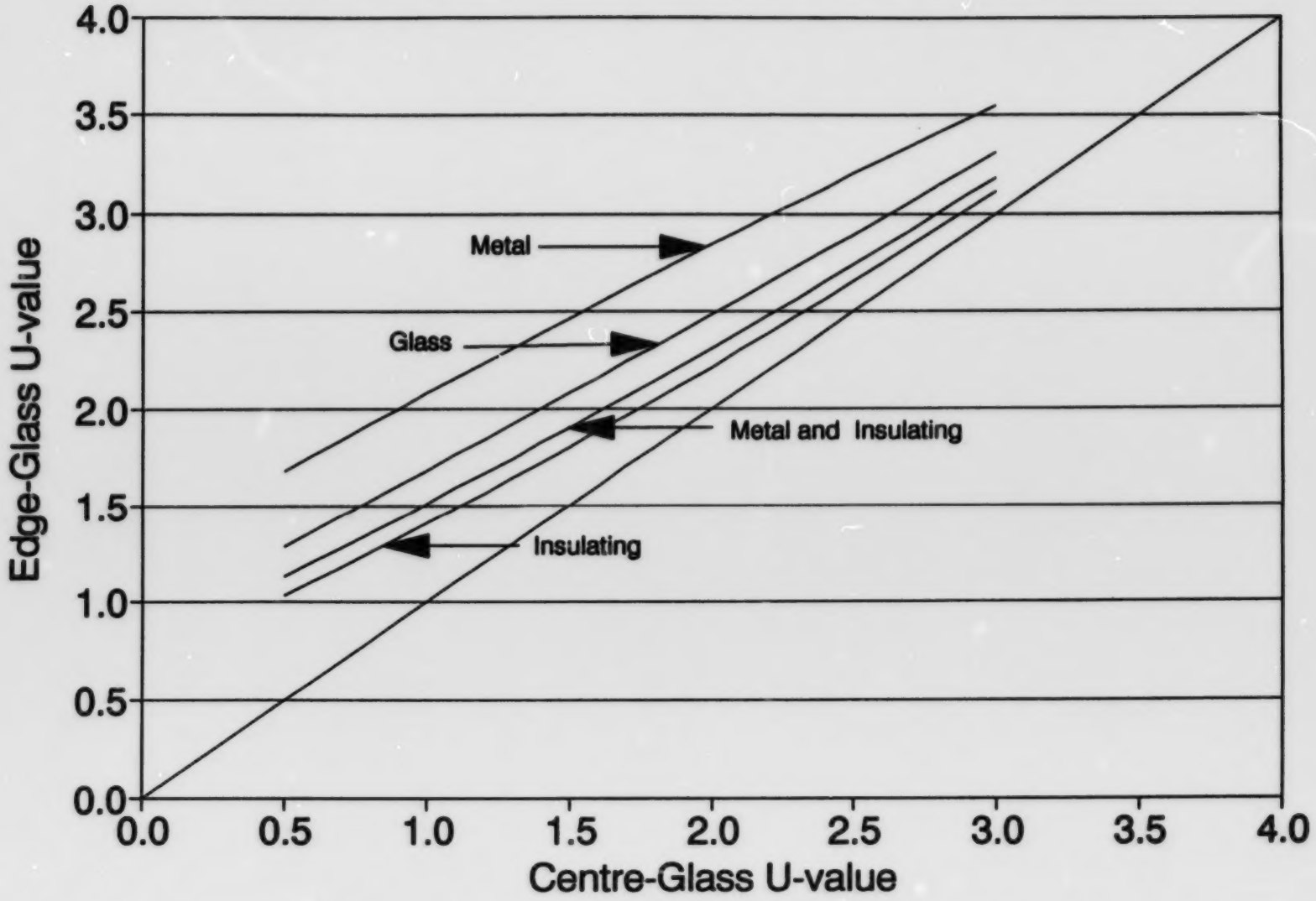
As was discussed in Section 1, it is necessary to develop a table of frame U-values to use the manual method for estimating window heat loss. It was shown in Section 2 that the FRAME program can provide reasonable estimates of frame U-values. The task remains to produce a table that adequately represents the range of commercially available window products.

There are hundreds of window manufacturers across Canada, each producing windows of different design, operating style, material composition and size. It would not be practical to generate frame U-values for all possible window frames; rather, the thousands of frame designs must be divided into groups of similar construction. The frame U-value for each group should be representative of a typical or average window in the group; it should be recognized that individual products will have frame U-values slightly better or slightly worse than this average.

Table 6. Coefficients for Edge-of-Glass U-value Equation

	A	B	C
Metal	1.266	0.842	-0.027
Insulating	0.681	0.682	0.043
Glass	0.897	0.774	0.010
Metal + Insul.	0.769	0.706	0.033

FIGURE 8: Edge-Glass U-value vs. Centre-Glass



Hogan [1990] has categorized the results of 64 window U-value tests and compared them to the values given in the 1989 ASHRAE Handbook of Fundamentals. Although some of the discrepancy is no doubt due to the variation and quality of the many testing labs, the test results suggest generic product categories. For wood-framed windows, double-hung had higher U-values, and casement and awning windows had lower U-values, than the single number given in the ASHRAE Handbook. Both sliding and fixed wood windows tended to have U-values close to the ASHRAE value.

There were not enough test values given in Hogan's paper to develop categories for vinyl, aluminum and thermally-broken aluminum windows, but previous simulation work can provide some guidance in this regard. Enermodal [1990] has found that frame heat loss in most windows is controlled by a single component, or "controlling resistance": only changes in this component have a significant effect on frame heat loss. For example, the "controlling resistance" in building walls is the insulation; changes to the exterior brick or interior drywall have little effect on wall heat loss.

For thermally-broken aluminum-framed windows, the resistance of the thermal break is of most importance in determining frame heat loss. Changes in the aluminum portions of the frame had almost no effect on heat loss. For aluminum-framed windows, the inside film coefficient provides most of the resistance to heat flow. The vinyl and wood frame are the controlling resistances in their respective windows. Thus, window frames should be divided into categories of equal controlling resistances (that is, equal lengths of the controlling resistance material). For thermally-broken aluminum windows, the length is the shortest distance across the thermal break. For wood and vinyl windows, the length is the shortest distance between the inside and the outside conditions (this distance depends on the thickness of the sealed glazing unit).

The design of the spacer can also have a significant effect on the frame heat loss in all but aluminum-framed windows [Carpenter and McGowan, 1989]. Spacer materials can be divided into two groups:metal and non-metal (i.e., high-conductivity and low-conductivity).

To summarize, frame U-values are a function of

- Material (wood, vinyl, aluminum and a combination of these materials)
- Operating Style (fixed, casement/awning, single/double hung and slider)
- Design (width of thermal break in the case of aluminum, or thickness of sealed glazing unit for wood and vinyl windows)
- Spacer (metal and non-metal)

We have used these parameters in categorizing frame U-values.

For a table of frame U-values to be generally applied, it is important that the frame heat loss be normalized by the correct factor. The U-values quoted in the ASHRAE Handbook are based on the projected area of the frame (i.e., normal to the direction of heat flow). It has been postulated that in some cases more consistent results may be obtained by normalizing frame heat loss according to surface area or perimeter length. To examine this possibility, picture window frame designs from several manufacturers were simulated and compared using all three normalizing methods. The results are given in Table 7.

Table 7 shows that, although the heat loss from frames of similar construction can vary by up to 50%, normalizing by projected area produces the most consistent results (i.e., the smallest coefficient of variation, or ratio of standard deviation to mean value, occurs when normalizing by projected area). It is interesting to note, however, that normalizing by surface area is slightly more consistent for the all-aluminum window. This difference is not significant enough to warrant using both normalizing methods, but it shows that heat loss in an aluminum frame is dependent on surface area, and this should be considered when evaluating (or designing) aluminum frames. Therefore, projected area will be used for the U-values in this report. This will also be consistent with published results from other sources [ASHRAE 1989, Hogan 1990, etc.].

3.4.2 Generating U-value Tables

The FRAME computer program was used to generate frame U-values for the categories discussed in Section 3.4.1. In each case, a drawing showing the frame cross-section was obtained from a major Canadian window manufacturer thought to be representative of that residential window category. Nevertheless, the U-value for a different manufacturer's frame may be higher or lower than the values given in this report. The window cross-sections are included in Appendix B along with the FRAME program representations.

For most of the frames, separate FRAME runs were required for each of the sill, head, jamb and meeting rail cross-sections. Rather than present a large cumbersome table with all these U-values, the individual U-values were combined assuming the outside window dimensions were 900 mm x 1200 mm (ASHRAE Type R). The combined frame U-value is appropriate for all windows with approximately the same width-to-height ratio, regardless of size (although the frame area and percentage frame will vary with size).

Table 7. A Comparison of U-value Normalizing Procedures for Picture Window Frames

Frame	Total Frame Heat Loss (Watts)	U-value, normalized according to proj. area [W/(m²*C)]	surf. area [W/(m²*C)]	perimeter [W/(m*C)]
Wood #1	19.09	2.70	0.64	0.12
Wood #2	17.13	2.77	1.05	0.11
Wood #3	15.77	2.70	0.59	0.10
Mean		2.72	0.76	0.11
Std Dev		0.03	0.27	0.008
S.D./Mean		0.01	0.27	0.07
TB Alum #1	69.01	4.38	2.90	0.53
TB Alum #2	46.09	4.46	2.54	0.32
TB Alum #3	52.75	4.68	3.03	0.37
Mean		4.51	2.82	0.41
Std Dev		0.13	0.21	0.09
S.D./Mean		0.03	0.07	0.22
Aluminum #1	132.67	8.42	5.58	1.02
Aluminum #2	95.70	9.26	5.28	0.67
Aluminum #3	95.46	8.47	5.48	0.67
Mean		8.72	5.45	0.79
Std Dev		0.38	0.12	0.16
S.D./Mean		0.04	0.02	0.21

The windows were categorized as being one of four operating types: picture, hinged (which includes awning, projected, and casement, and in most cases has the same profile as fixed windows), sliding (including horizontal sliders and double- and single-hung windows), and semi-sashless sliders (which are also referred to as "gliding" windows). The U-values for windows in these four categories are given in Tables 8, 9, 10 and 11. The percentage of frame and equivalent frame heights are also tabulated, to allow comparison with windows not included in these tables. The film coefficients used in modelling the frames were determined using the VISION program at ASHRAE winter design conditions.

Figures 9, 10, and 11 graphically present some of the results from the tables. For the windows studied, semi-sashless slider and hinged windows had U-values lower than those of picture and I.G. sliders. Although at first it seems surprising that picture frames have a high U-value, it should be remembered that they have the smallest projected area and, therefore, the smallest total heat loss. Fibreglass frames generally are the most resistive to heat flow, with aluminum and thermally broken aluminum frames having the lowest resistance to heat flow.

3.4.3 Comparison With Existing Results

It is difficult to compare the frame heat loss given in the ASHRAE Handbook to the results of this report because the frame profiles used in the ASHRAE Handbook are confidential. We have listed below the range of U-values for the frame types listed in the ASHRAE handbook. The ASHRAE values fall within the range of the FRAME predicted U-values.

	Aluminum	TB Alum	Wood/Vinyl
ASHRAE	10.8	5.7	2.3
FRAME	7.18-12.94	3.59-9.27	2.03-3.56

The frame U-values quoted in Hogan [1990] should not be compared directly to these results, as the frame profiles used in the Hogan report are not known, and because the method of backing out the frame U-values from his results does not work due to a large error band (12% of the frame U-values quoted in that document are negative). The trends from Hogan [1990] are the same as those described in Section 3.4.2, double-hung frames have higher U-values than the ASHRAE value, and casement/awning frames have lower U-values. As well, the semi-sashless sliders and picture windows tend to have frame U-values close to the ASHRAE values. U-values of the all-aluminum frames were found to vary greatly, depending on the total surface area of the frame.

Table 8. FRAME Calculated U-Values for Picture Window Frames

Frame Design	Thickness IG or TB[a]	Spacer Type	Percent Frame (%)[b]	Average Frame Height (mm)	U-Value [W/(m²•C)][c]
P1 Aluminum	36 mm	all	11.3	29.9	7.18[d]
P2 Aluminum	104 mm	all	13.0	34.5	12.94
P3 Aluminum with T.B.	5 mm	alum.	13.0	34.5	9.27
P3 Aluminum with T.B.	5 mm	ins.	13.0	34.5	7.82
P4 Aluminum with T.B.	9 mm	alum.	9.5	25.0	6.58
P4 Aluminum with T.B.	9 mm	ins.	9.5	25.0	5.20
P5 Aluminum with T.B.	33 mm	alum.	14.4	38.4	5.06
P5 Aluminum with T.B.	33 mm	ins.	14.4	38.4	3.77
P6 Fiberglass	18 mm	alum.	17.1	46.0	2.31
P6 Fiberglass	18 mm	ins.	17.1	46.0	2.06
P7 Fiberglass	34 mm	alum.	17.1	46.0	1.98
P7 Fiberglass	34 mm	ins.	17.1	46.0	1.58
P8 Vinyl	18 mm	alum.	16.0	42.9	2.48
P8 Vinyl	18 mm	ins.	16.0	42.9	2.10
P9 Vinyl	34 mm	alum.	16.0	42.9	2.51
P9 Vinyl	34 mm	ins.	16.0	42.9	1.87
P10 Vinyl-Rein.	18 mm	alum.	16.0	42.9	2.95
P10 Vinyl-Rein.	18 mm	ins.	16.0	42.9	2.57
P11 Vinyl-Rein.	34 mm	alum.	16.0	42.9	2.81
P11 Vinyl-Rein.	34 mm	ins.	16.0	42.9	2.25
P12 Wood	18 mm	alum.	14.7	39.3	2.78
P12 Wood	18 mm	ins.	14.7	39.3	2.37
P13 Wood	34 mm	alum.	14.7	39.3	2.55
P13 Wood	34 mm	ins.	14.7	39.3	1.88
P14 Wood-Al Clad	18 mm	alum.	14.7	39.3	2.96
P14 Wood-Al Clad	18 mm	ins.	14.7	39.3	2.46
P15 Wood-Al Clad	34 mm	alum.	14.7	39.3	2.68
P15 Wood-Al Clad	34 mm	ins.	14.7	39.3	1.96

Notes:

a. "Thickness" refers to the dimension perpendicular to the plane of the window, and is the thickness of the IG unit (for non-metal frames), the length of the thermal break (in the case of TB aluminum frames), or the thickness of the frame parallel to heat flow (in the case of all-aluminum frames).

b. "Percent frame" is based on a standard 900x1200 mm residential window.

c. All U-values were generated using ASHRAE winter design conditions:
Outside temperature = -18°C, surface coefficient = 34.48 W/(m²•C)
Inside temperature = 21°C, surface coefficient = 7.58 W/(m²•C)

d. U-values for all-aluminum windows show wide variation, depending on the window design, and especially on total surface area of the frame.

Table 9. FRAME Calculated U-Values for Hinged Window Frames

Frame Design	Thickness IG or TB[a]	Spacer Type	Percent Frame (%)[b]	Average Frame Height (mm)	U-Value [W/(m²•C)][c]
H1 Aluminum	-	all	22.9	62.6	12.03[d]
H2 Aluminum with T.B.	5 mm	alum.	37.4	107.1	4.38
H2 Aluminum with T.B.	5 mm	ins.	37.4	107.1	4.24
H3 Aluminum with T.B.	9 mm	alum.	24.6	67.6	4.10
H3 Aluminum with T.B.	9 mm	ins.	24.6	67.6	3.60
H4 Aluminum with T.B.	18 mm	alum.	26.2	72.4	3.59
H4 Aluminum with T.B.	18 mm	ins.	26.2	72.4	3.39
H5 Fiberglass	18 mm	alum	25.4	70.0	2.47
H5 Fiberglass	18 mm	ins.	25.4	70.0	2.17
H6 Vinyl	18 mm	alum.	25.1	69.1	2.03
H6 Vinyl	18 mm	ins.	25.1	69.1	1.78
H7 Vinyl	34 mm	alum.	25.1	69.1	1.87
H7 Vinyl	34 mm	ins.	25.1	69.1	1.53
H8 Vinyl-Rein.	18 mm	alum.	25.1	69.1	2.35
H8 Vinyl-Rein.	18 mm	ins.	25.1	69.1	2.11
H9 Vinyl-Rein.	34 mm	alum.	25.1	69.1	2.16
H9 Vinyl-Rein.	34 mm	ins.	25.1	69.1	1.84
H10 Wood	18 mm	alum.	28.1	78.1	2.33
H10 Wood	18 mm	ins.	28.1	78.1	2.09
H11 Wood	34 mm	alum.	28.1	78.1	2.03
H11 Wood	34 mm	ins.	28.1	78.1	1.66
H12 Wood-Al Clad	18 mm	alum.	28.1	78.1	2.36
H12 Wood-Al Clad	18 mm	ins.	28.1	78.1	2.10
H13 Wood-Al Clad	34 mm	alum.	28.1	78.1	2.08
H13 Wood-Al Clad	34 mm	ins.	28.1	78.1	1.69

Notes:

a. "Thickness" refers to the dimension perpendicular to the plane of the window, and is the thickness of the IG unit (for non-metal frames) or the length of the thermal break (in the case of aluminum frames).

b. "Percent frame" is based on a standard 900x1200 mm residential window.

c. All U-values were generated using ASHRAE winter design conditions:
Outside temperature = -18°C, surface coefficient = 34.48 W/(m²•C)
Inside temperature = 21°C, surface coefficient = 7.58 W/(m²•C)

d. U-values for all-aluminum windows show wide variation, depending on the window design, and especially on total surface area of the frame.

Table 10. FRAME Calculated U-Values for Sliding Window Frames

Frame Design	Thickness IG or TB[a]	Spacer Type	Percent Frame (%)[b]	Average Frame Height (mm)	U-Value [W/(m²•C)][c]
S1 Aluminum	-	all	25.0	48.1	14.36[d]
S2 Aluminum with T.B.	20 mm	alum.	24.0	46.0	5.35
S2 Aluminum with T.B.	20 mm	ins.	24.0	46.0	4.67
S3 Fiberglass[e]	18 mm	alum	33.6	66.3	2.53
S3 Fiberglass[e]	18 mm	ins.	33.6	66.3	2.24
S4 Vinyl	18 mm	alum.	31.8	62.4	3.29
S4 Vinyl	18 mm	ins.	31.8	62.4	2.92
S4 Vinyl-Rein.	18 mm	alum.	31.8	62.4	3.56
S4 Vinyl-Rein.	18 mm	ins.	31.8	62.4	3.21
S5 Wood	18 mm	alum.	29.9	58.4	3.38
S5 Wood	18 mm	ins.	29.9	58.4	3.06
S6 Wood	34 mm	alum.	29.9	58.4	3.07
S6 Wood	34 mm	ins.	29.9	58.4	2.55
S7 Wood-Al Clad	18 mm	alum.	29.9	58.4	3.55
S7 Wood-Al Clad	18 mm	ins.	29.9	58.4	3.16
S8 Wood-Al Clad	34 mm	alum.	29.9	58.4	3.25
S8 Wood-Al Clad	34 mm	ins.	29.9	58.4	2.65

Table 11. FRAME Calculated U-Values for Semi-sashless Sliding Window Frames

Frame Design	Thickness IG or TB[a]	Percent Frame (%)[b]	Average Frame Height (mm)	U-Value [W/(m²•C)][c]
S9 Aluminum	-	31.7	62.2	7.10[d]
S9 Aluminum with T.B.	10 mm	31.7	62.2	4.76
S10 Aluminum with T.B.	33 mm	24.1	46.2	3.82
S11 Aluminum with T.B.	50 mm	18.1	34.1	3.68
S12 Fiberglass	18 mm	23.7	45.4	3.28
S13 Wood/PVC	18 mm	16.9	31.8	2.02
S14 Wood/PVC	34 mm	16.9	31.8	1.19
S15 Wood/PVC-Al Clad	18 mm	16.9	31.8	2.04
S16 Wood/PVC-Al Clad	34 mm	16.9	31.8	1.21

Notes:

a. "Thickness" refers to the dimension perpendicular to the plane of the window, and is the thickness of the IG unit (for non-metal frames) or the length of the thermal break (in the case of aluminum frames).

b. "Percent frame" is based on a standard 900x1200 mm residential window.

c. All U-values were generated using winter design conditions:
Outside temperature = -18°C, surface coefficient = 34.48 W/(m²•C)
Inside temperature = 21°C, surface coefficient = 7.58 W/(m²•C)

d. U-values for all-aluminum windows show wide variation, depending on the window design, and especially on total surface area of the frame.

e. Frame cavities filled with fibreglass insulation.

Figure 9:

Wood Window Frames
(Double Glazed)

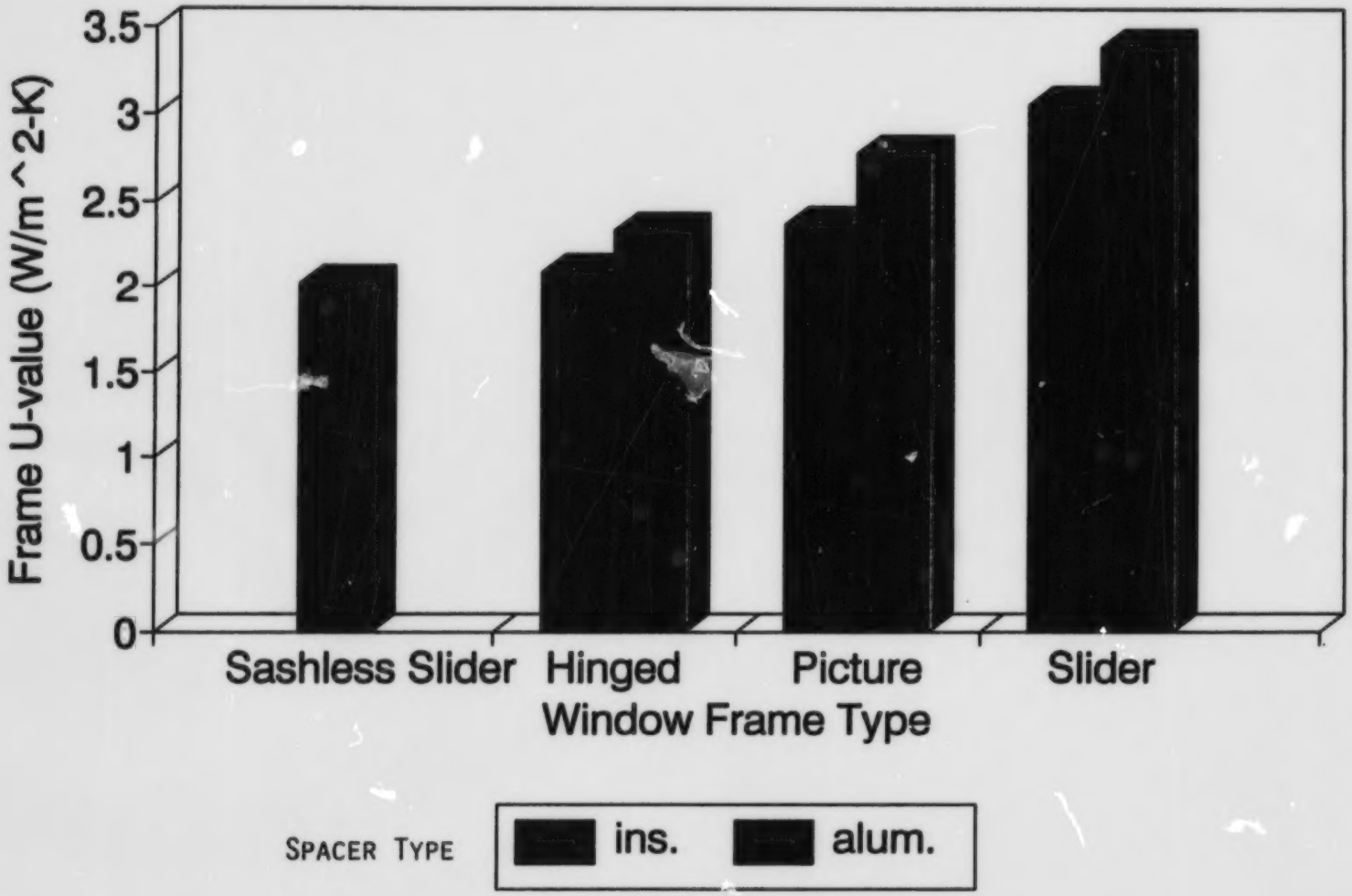


Figure 10:

Aluminum Window Frames
(Double Glazed - 10 mm Thermal Break)

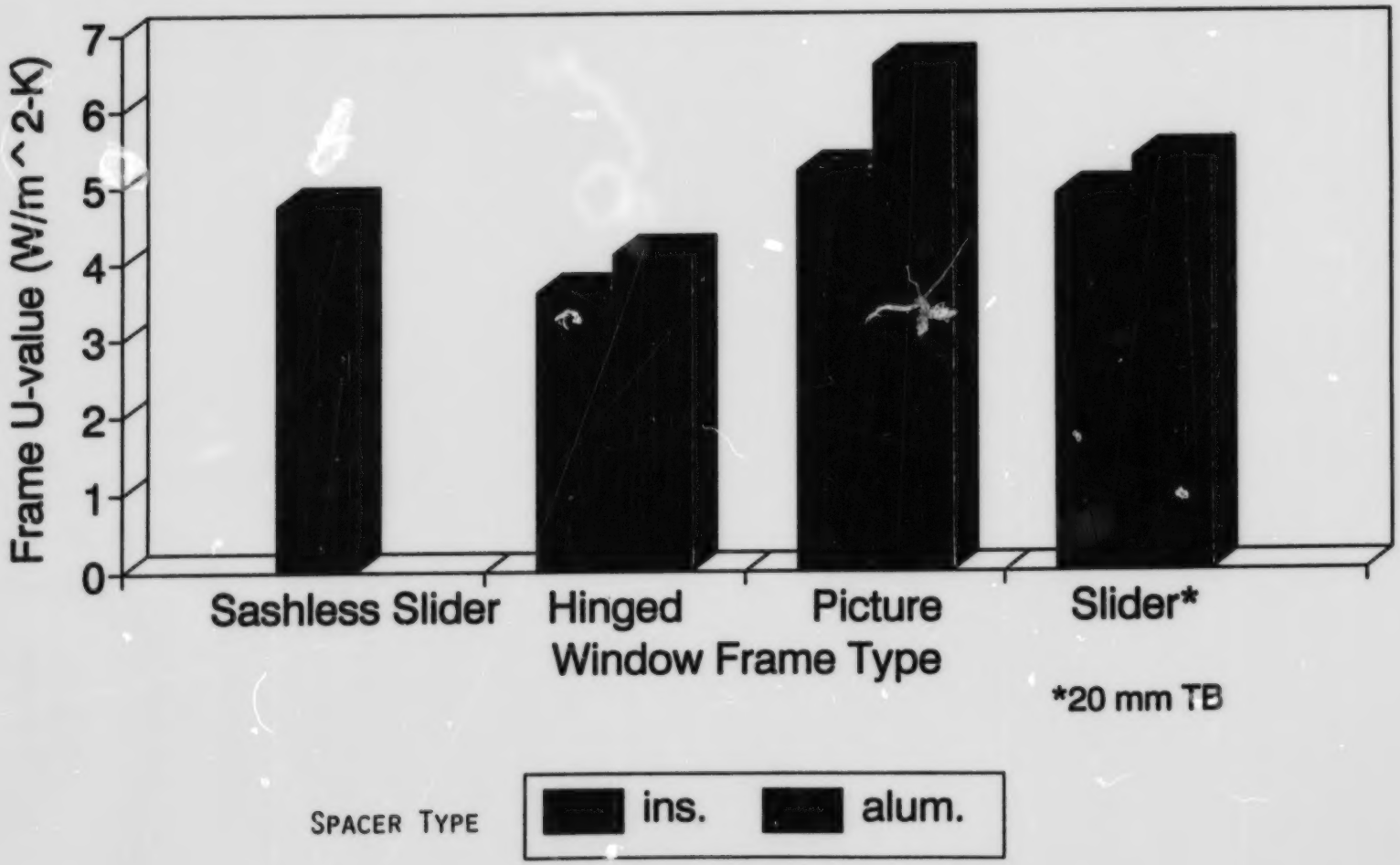
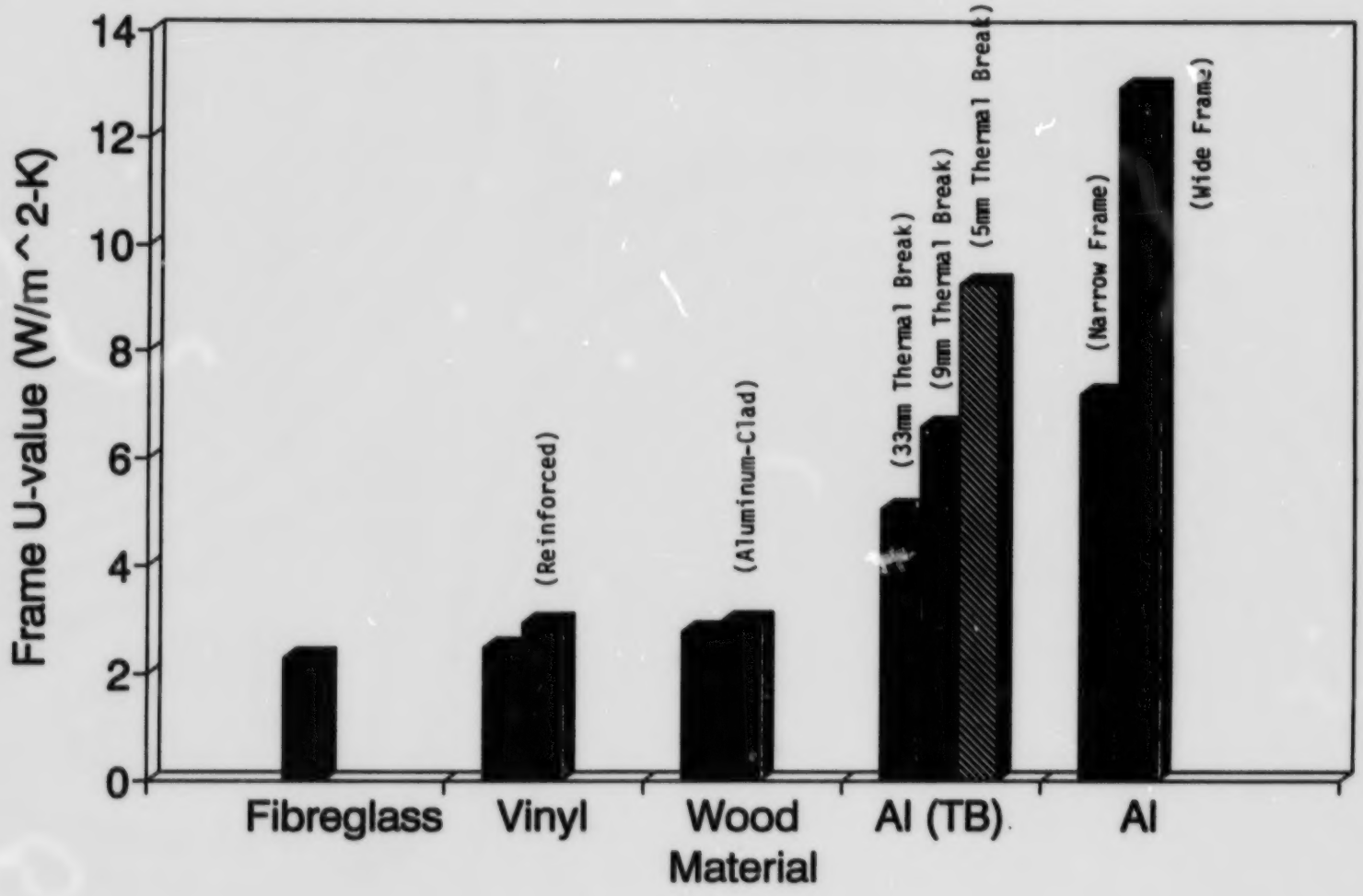


Figure 11:

Picture Window Frames
(Double Glazed Aluminum Spacer)



4. DETERMINATION OF TOTAL WINDOW SHGC

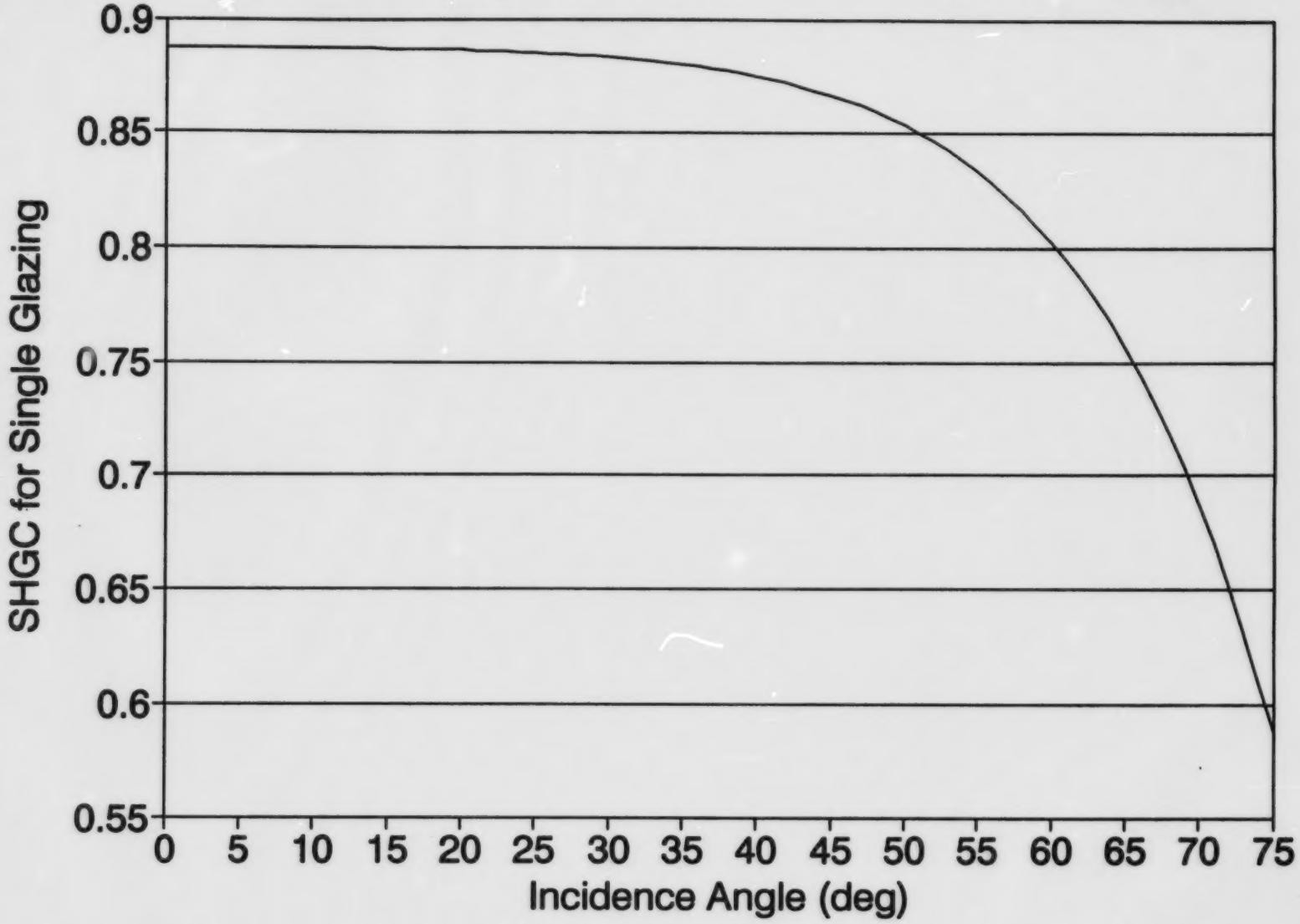
4.1 Methodology

The solar heat gain coefficient (SHGC) is the fraction of the solar radiation incident on the window that ends up in the building including the solar radiation that is absorbed by the glazings and is conducted or reflected into the building. Some sources prefer to use the quantity "Shading Coefficient" which is the window SHGC divided by the SHGC for a reference single-glazed window. The SHGC is a characteristic of each glazing type and varies slightly with angle of incidence. The conventional practice for determining total window SHGC is to assume the frame SHGC is zero and the edge-of-glass value is the same as the centre-of-glass value. The centre-of-glass SHGC of the window is typically evaluated at one weather condition and assumed constant over the heating season. This methodology raises three important questions: how is the SHGC affected by variation in the outdoor temperature, the outside film coefficient, and the incident radiation level; how does the SHGC vary with the angle of incidence between the beam radiation and the normal to the glazing; and how does the edge-of-glass and frame heat loss affect the SHGC for a window (i.e., does the frame have a significant SHGC?).

This section uses the VISION and FRAME programs to address the above questions. The VISION program quickly and accurately calculates the shading coefficient for the centre-glass portion of a window. The SHGC can then be calculated by multiplying the shading coefficient by the SHGC for the single-glazed reference window. Figure 12 shows the SHGC angular dependence of the single-glazed reference window based on information contained in the 1989 ASHRAE Handbook of Fundamentals. The VISION program was used to study the effect of outdoor temperature, solar radiation level, outside film coefficient and angle of incidence on the SHGC of a window. The FRAME program was used to examine the effect of the frame and edge-of-glass heat loss on the SHGC, and to determine whether window frames have a significant SHGC.

While it is recognized that the SHGC is a function of many parameters, the emphasis in this report is whether these variations are significant enough to warrant consideration or if excluding their effects gives a certain type of window an unfair advantage when comparing energy performance.

FIGURE 12: Single Glazing SHGC vs. Incident Angle



4.2 Centre-Glazing SHGC

4.2.1 Effect of Weather Conditions

The variation of the centre-of-glass SHGC with outdoor temperature, solar radiation level, and outside film coefficient was investigated using the VISION program. A double glazing with one low-emissivity coating (e = 0.09) was modelled, varying each of the three parameters independently. The indoor temperature and angle of incidence were held constant at 21 °C and zero degrees, respectively, for all simulations. The VISION program calculates the outside film coefficient from the outside wind speed, so the wind speed was varied to achieve the desired range of conditions.

First the outdoor temperature was varied, while the wind speed was set at 6.7 m/s (ASHRAE winter condition) and the solar radiation level was held constant at 783 W/m^2 (ASHRAE summer condition: the winter condition of 0 W/m^2 was not appropriate). The outdoor temperature was set to the following values: -18°C, -10°C, 0°C, 10°C, and 20°C. Table 12 presents the SHGC for each temperature: the change in the SHGC was less than 0.7% from one extreme to the other.

Next, the solar radiation level was varied, while the outdoor temperature was held constant at -18°C and the wind speed set to 6.7 m/s (ASHRAE winter conditions). The solar radiation level was set to 783 W/m^2, 600 W/m^2, 400 W/m^2, and 200 W/m^2. The change in the SHGC was less than 0.2% between 783 W/m^2 and 200 W/m^2 (see Table 12).

Finally, the wind speed was varied, while the outdoor temperature was held constant at -18°C and the solar radiation level was set to 783 W/m^2. The wind speed was set to 6.7 m/s, 3.35 m/s, 2.2 m/s, and 1.0 m/s. As shown in Table 12, the SHGC varied by less than 0.5% from 6.7 m/s to 1.0 m/s.

These results indicate that the outdoor temperature, solar radiation level, and outside film coefficient have very little effect on untinted window SHGC: in all cases, the effect was less than 0.7% for any one parameter. (Larger effects would probably be found in heavily tinted windows commonly used in commercial buildings.)

4.2.2 Effect of Off-Normal Incidence

The variation of SHGC for off-normal angles of incidence can easily be determined with the VISION program. The VISION program models one-dimensional heat transfer through the centre-glass

Table 12: Variation in SHGC with Weather Conditions

To (°C)	SHGC				
-18	0.652	T_i	=	21	C
-10	0.652	Rad.	=	783	W/m^2
0	0.653	Wind	=	6.7	m/s
10	0.654				
20	0.656				

Rad. (W/m^2)	SHGC				
783	0.652	T_i	=	21	C
600	0.653	T_o	=	-18	C
400	0.653	Wind	=	6.7	m/s
200	0.653				

Wind (m/s)	SHGC				
6.7	0.652	T_i	=	21	C
3.4	0.650	T_o	=	-18	C
2.2	0.649	Rad.	=	783	W/m^2
1.0	0.648				

portion of the window. Eight glazing system configurations were modelled with VISION to study the effect of the angle of incidence of the beam solar radiation on the SHGC. The eight glazing systems included: a double glazing (DG), a double glazing with one low-emissivity coating (DGLE), a double glazing with two low-emissivity coatings (DGDE), a triple glazing (TG), a triple glazing with one low-emissivity coating (TGLE), a triple glazing with two low-emissivity coatings (TGDE), and a double glazing with two Heat Mirror films (QGHM). All of the low-emissivity coatings used had an emissivity of 0.09.

The SHGC for the eight glazing system configurations were calculated as a function of the beam radiation incidence angle. The incident angle was varied in 15-degree increments from 0 to 90 degrees. Table 13 lists the results for the eight glazing systems. An off-normal incidence angle factor (F_i) was calculated by dividing each SHGC by the value for normally incident radiation. The off-normal incidence angle factor can be used to modify the solar heat gain equation:

$$Q_{sol} = SHGC_n * F_i * I_t$$

where $SHGC_n$ is the window solar heat gain coefficient at a normal incidence angle

Table 13 also includes the F_i for the eight glazing systems.

The off-normal incidence factor has been characterized by the following relationship [Duffie and Beckman, 1980]:

$$F_i = 1 - A * [(1/\cos(B)) - 1] \quad (4)$$

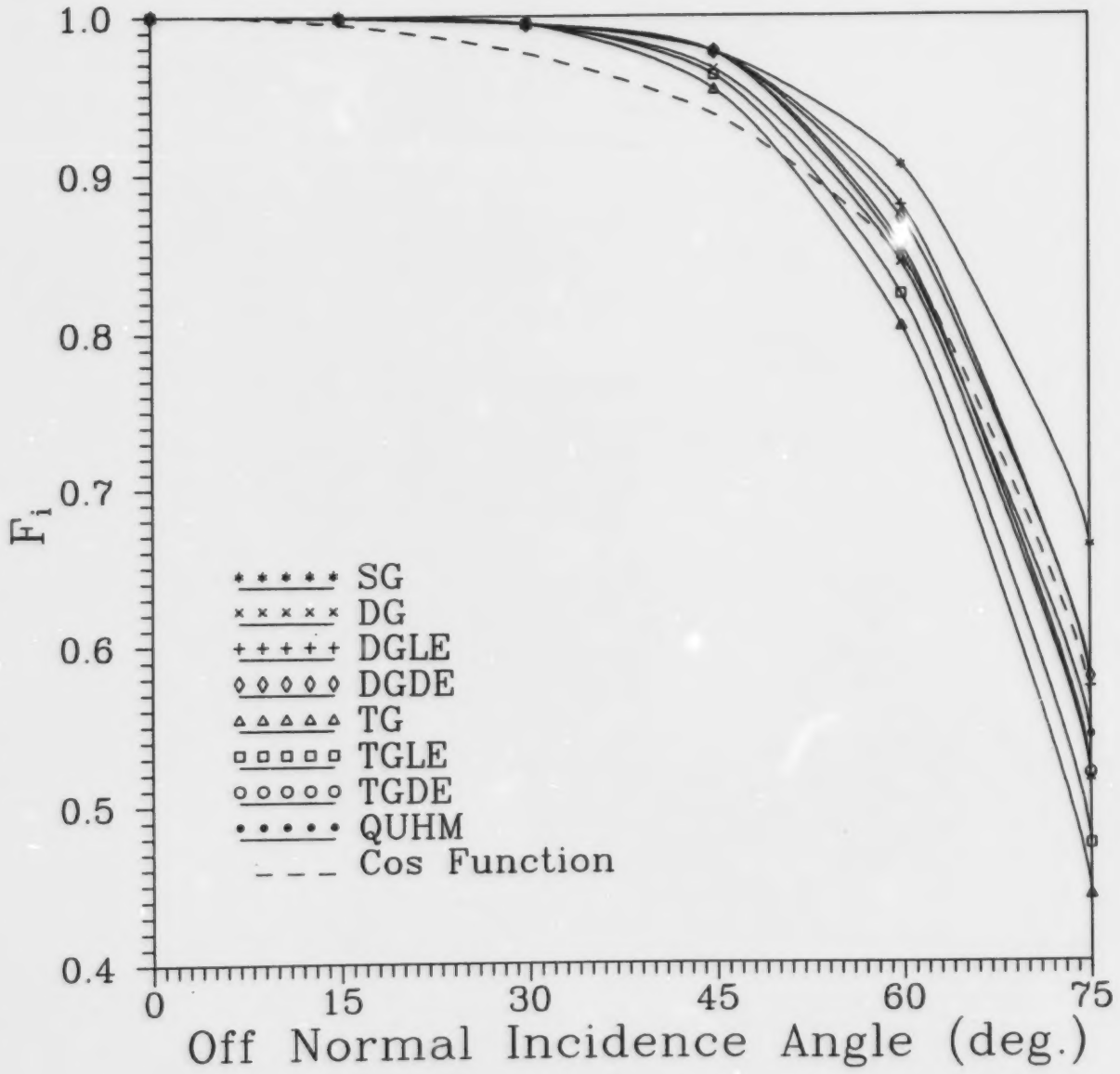
where A is a constant
B is the angle of incidence

The value of the constant A was determined for each incident of the seven glazing systems. A value of 0.153 for A results in the least error from the average values of F_i. The off-normal incidence factor for eight glazing systems, and as calculated using Equation 4, are plotted in Figure 13. The figure shows that, at off-incidence angles up to 30°, all the glazings have a value of F_i equal to 1.0. At an incidence angle of 60%, however, there is a 15% difference between the high and low values.

Table 13: Variation in SHGC with Angle of Incidence

GLAZING TYPE	SOLAR HEAT GAIN COEFFICIENT (SHGC) ANGLE BETWEEN NORMAL TO GLAZING AND BEAM RADIATION						
	0	15	30	45	60	75	90
SG	0.887	0.887	0.883	0.867	0.803	0.588	
DG	0.799	0.798	0.795	0.771	0.674	0.411	0.000
DGLE	0.648	0.647	0.645	0.633	0.570	0.370	0.000
DGDE	0.488	0.488	0.486	0.477	0.425	0.282	0.000
TG	0.719	0.718	0.716	0.685	0.578	0.317	0.000
TGLE	0.595	0.594	0.592	0.572	0.490	0.282	0.000
TGDE	0.488	0.488	0.486	0.477	0.417	0.253	0.000
QGHM	0.293	0.293	0.292	0.286	0.249	0.159	0.000
	OFF-NORMAL INCIDENCE FACTOR (Fi)						
SG	1.000	0.999	0.995	0.977	0.905	0.662	
DG	1.000	0.999	0.995	0.966	0.844	0.515	0.000
DGLE	1.000	0.999	0.995	0.977	0.880	0.572	0.000
DGDE	1.000	0.999	0.995	0.977	0.872	0.578	0.000
TG	1.000	0.999	0.995	0.953	0.804	0.442	0.000
TGLE	1.000	0.999	0.995	0.962	0.824	0.474	0.000
TGDE	1.000	0.999	0.995	0.977	0.855	0.518	0.000
QGHM	1.000	0.999	0.995	0.977	0.850	0.542	0.000

FIGURE 13: SHGC Off Normal Incidence Correction



Duffie and Beckman [1980] have produced graphs of average monthly incidence angles for a range of orientations and latitudes. The average incident angle for beam solar radiation on a south-facing vertical surface over the heating season for latitudes of between 40 and 50 degrees is approximately 45 degrees. The average incidence angle for diffuse and reflected radiation is also close to 45 degrees. Therefore, an average incidence angle of 45 degrees is typical for most Canadian locations. At this angle there is not a significant difference in incidence angle correction between the glazing types. Thus, it is recommended that Equation 4 be used to correct for off-angle incidence, regardless of glazing type. The average incidence angle correction for south-facing surfaces is 0.95 (the value for 45 degrees).

4.2.3 Table of Centre-of-Glass SHGC

The centre-of-glass SHGC for each of the glazing systems listed in Table 5 was calculated with the VISION program. The SHGCs were calculated with the incident radiation normal to the window, at an outdoor temperature of -18°C and an outside film coefficient corresponding to a 6.7 m/s wind. Calculated values of centre-of-glass SHGCs are listed in Table 14. (Note: argon gas fills and pane spacing had a negligible effect on SHGC.)

4.3 Frame and Edge-of-Glass SHGC

The conventional procedure for calculating the SHGC for a window assumes that the frame SHGC is zero and that the edge-of-glass SHGC is the same as the centre-of-glass. This portion of the study will examine the effect of the frame and edge-of-glass heat transfer on the total-window SHGC.

A double glazing was modelled in three frame types with and without solar radiation, to study the effect of the frame and edge-of-glass heat transfer on the window SHGC. The radiation was initially modelled normal to the window. The three frame types modelled were aluminum, thermally-broken aluminum, and wood. The cross-sections for these frames are given in Appendix B (P2, P3, and P12 respectively). The frames were simulated using the FRAME program to model the two-dimensional heat transfer through the edge-of-glass and frame of the window.

The solar heat gain through the frame was determined from the reduction of the frame heat loss as a result of the solar radiation incident on the frame. The frame SHGC was defined as the solar heat gain through the frame, divided by the solar radiation incident on the projected area of the frame. The solar heat gain through the edge-of-glass included the solar radiation transmitted through the glazing

Table 14. Centre-Glazing SHGC as Calculated with VISION

GLAZING SYSTEM		SHGC
Single		
Clear Glass		0.87
Tinted Glass		0.74
Double Glass		
Clear		0.78
e = 0.09	on one surface	0.64
e = 0.20	on one surface	0.75
e = 0.35	on one surface	0.72
Tinted*		0.64
e = 0.09	on one surface	0.51
e = 0.20	on one surface	0.60
e = 0.35	on one surface	0.58
Triple Glass		
Clear		0.70
e = 0.09	on one surface	0.57
e = 0.20	on one surface	0.67
e = 0.35	on one surface	0.65
Tinted*		0.57
e = 0.09	on one surface	0.46
e = 0.20	on one surface	0.54
e = 0.35	on one surface	0.52
Clear		
e = 0.09	on two surfaces	0.44
e = 0.20	on two surfaces	0.66
e = 0.35	on two surfaces	0.57
Tinted*		
e = 0.09	on two surfaces	0.39
e = 0.20	on two surfaces	0.51
e = 0.35	on two surfaces	0.48
Double Glass plus		
One Heat Mirror™ 66		0.40
One Heat Mirror™ 88		0.69
Two Heat Mirror™ 66		0.27
Two Heat Mirror™ 88		0.50

* suitable for exterior lite of grey or green 3mm glass, interior lite clear

system and absorbed in the room, plus the reduction in the heat loss through the edge-of-glass as a result of the incident solar radiation. The edge-of-glass SHGC was calculated by dividing the edge-of-glass solar heat gain by the incident solar radiation. Table 15 compares the SHGC for the conventional calculation procedure with the results for the three frames modelled in this study.

The difference in the SHGC from the conventional calculation procedure and the results using frames modelled in this study are also included in Table 15. The SHGC for the wood frame window showed no difference from the conventional procedure, (the decrease in SHGC for the edge-of-glass matched the increase in the frame value) and one would expect similar results for frames of similar U-value (e.g., vinyl, fibreglass). The SHGCs for windows using thermally-broken aluminum and aluminum frames showed an increase of 1.6% and 2.4%, respectively, over the conventional calculation procedure. The SHGCs for the thermally-broken aluminum and aluminum frames were .10 and .14, respectively.

The next step in the study was to model the frames with the solar radiation at an incident angle of 45 degrees. The wood frame was eliminated from any further study because there was no change in the window SHGC from the conventional procedure with the solar radiation normal to the window. The aluminum and thermally-broken aluminum frames were both modeled with the radiation at an angle of 45 degrees and compared to the previous results without the incident radiation. The frame solar heat gain was calculated the same way as it was with the normal radiation. The edge-of-glass solar heat gain included the solar radiation transmitted through the glazing and absorbed in the room, less the transmitted radiation incident on the inside portion of the frame (which was included in the frame model), plus the reduction in the heat loss through the edge-of-glass. The SHGCs for the two frame types with the radiation at an incident angle of 45 degrees are compared to the conventional calculation procedure in Table 16. The SHGCs for both frame types increased by 4.4% over the conventional calculation procedure. However, this increase may be overstated, as the frame may shade the glass reducing the solar heat gain into the room.

The above analysis used an outside film coefficient of 34.0 W/(m^2•C) (corresponding to a 6.7 m/s wind) in both cases. This part of the study investigated the effect of the outside film coefficient on the frame and edge-of-glass heat transfer and the resulting effect on the window SHGC. The aluminum frame was modelled with outside film coefficients of 20 and 16 W/(m^2•C), to represent more realistic wind conditions (4.5 and 3.3 m/s, respectively). In each case the frame was modelled once with solar radiation normal to the window and once with no solar radiation.

Table 15: Frame and Edge-of-Glass SHGC for Solar Radiation Normal to the Window

FRAME TYPE	ALUMINUM		THERMALLY BROKEN ALUMINUM		WOOD	
CALCULATION METHOD	CONV.*	MOD.**	CONV.	MOD.	CONV.	MOD.
SHGC						
Centre-of-Glass	0.783	0.783	0.783	0.783	0.783	0.783
Edge-of-Glass	0.783	0.777	0.783	0.775	0.783	0.765
Frame	0.000	0.138	0.000	0.100	0.000	0.021
Window	0.681	0.698	0.681	0.693	0.635	0.635
% Increase		2.4		1.6		0.0

* Conventional Calculation

** Modified Calculation

Conditions: h_i = 7.5 and h_o = 34.4 W/(m²*C)

Table 16: Frame and Edge-of-Glass SHGC for Radiation at 45 Degrees to Glazing

	CALCULATION METHOD			
SHGC	CONVENTIONAL ALUMINUM FRAME	MODIFIED ALUMINUM FRAME	CONVENTIONAL ALUMINUM FRAME	MODIFIED THERMALLY BROKEN ALUMINUM FRAME
Centre-of-Glass	0.783	0.783	0.783	0.783
Edge-of-Glass	0.783	0.791	0.783	0.791
Frame	0.000	0.226	0.000	0.228
Window	0.681	0.712	0.681	0.713
% Increase		4.4		4.4

Conditions: h_i = 7.5 and h_o = 34.4 W/(m^2*C)

Table 17: Variation in Frame and Edge-of-Glass SHGC with Outside Film Coefficient for Aluminum Framed Window

	CALCULATION METHOD			
SHGC	CONVENTIONAL	MODIFIED (h_o = 34.0)	MODIFIED (h_o = 20.0)	MODIFIED (h_o = 16.0)
Centre-of-Glass	0.783	0.783	0.783	0.783
Edge-of-Glass	0.783	0.777	0.789	0.795
Frame	0.000	0.138	0.203	0.232
Window	0.681	0.698	0.709	0.714
% Increase		2.4	3.9	4.6

Conditions: h_i = 7.5 W/(m^2*C), normal incidence

The SHGCs for the three outside film coefficients were compared to the conventional calculation procedure, and are included in Table 17. The increase in the SHGC over the conventional procedure ranges from 2.4% to 4.6%.

These results indicate that the edge-of-glass heat transfer has very little effect on the centre-glazing SHGC and can be ignored. The frame SHGC for wooden frames is negligible and has less than a 5% effect on windows with aluminum or thermally-broken aluminum frames. Analysis of the simulations revealed that the frame SHGC is well characterized as a linear function of frame U-value. The following equations are recommended:

$$SHGC_{fr} = 0.015 * a_{fr} * U_{fr} \quad \text{for 6.7 m/s wind} \qquad (5)$$
$$= 0.025 * a_{fr} * U_{fr} \quad \text{for 3.3 m/s wind}$$

where a_{fr} is the solar absorptivity of the frame (0.9 for dark frames, 0.2 for white frames)
U_{fr} is the frame heat loss coefficient in $W/(m^2*C)$.

5. MANUAL CALCULATION PROCEDURE FOR TOTAL WINDOW U-VALUE AND SHGC

5.1 Procedure

This section outlines the calculation procedure for total window U-value and SHGC at normal incidence angle and gives two example calculations. A total window U-value and SHGC calculation sheet has been included in Appendix C.

5.1.1 Total Window U-Value

Total window U-value is calculated as follows:

$$U_{total} = U_{cg} * F_{cg} + U_{eg} * F_{eg} + U_{fr} * F_{fr} \qquad (6)$$

where U_{total} = total window U-value
U_{cg} = centre-of-glass U-value
U_{eg} = edge-of-glass U-value
U_{fr} = frame U-value
F_{cg} = fraction centre-of-glass (based on projected area)
F_{eg} = fraction edge-of-glass (based on projected area)
F_{fr} = fraction frame (based on projected area)

Centre-of-glass U-value is taken from Table 5 for the appropriate glazing configuration (i.e., number of glazings, pane spacing, coatings, and fill gas).

Edge-of-glass U-value is calculated based on the correlation given in Section 3.3. The edge-of-glass U-value is a function of the centre-of-glass U-value and the spacer type. The correlation given in Section 3.3 is as follows:

$$U_{eg} = A + B * U_{cg} + C * U_{cg}^2 \qquad (3)$$

where A, B, and C are constants given in Table 6.

Table 6 includes constants for metal, insulating and fused glass spacers. Also included in Table 6 are the constants for a combination of one insulating spacer and one metal spacer in the same glazing unit.

Frame U-values are taken from Tables 8 through 11 for the appropriate frame type. The U-values in Tables 8 through 11 are for metal and insulating spacers only. When a fused glass spacer is used, the frame U-value is the sum of half the U-value with a metal spacer and half the U-value with an insulating spacer. When one insulating spacer and one metal spacer are used in the same glazing unit the frame U-value is the sum of 15% of the U-value with two metal spacers and 85% of the U-value with two insulating spacers.

The fraction frame is calculated as follows:

Picture and Hinged Windows

$$F_{fr} = [(H * W) - (H - 2 * H_{fr}) (W - 2 * H_{fr})] / (H * W) \quad (7)$$

Vertical Sliding Windows

$$F_{fr} = [((H/2) * W) - ((H/2) - 2 * H_{fr}) * (W - 2 * H_{fr})] / ((H/2) * W) \quad (8)$$

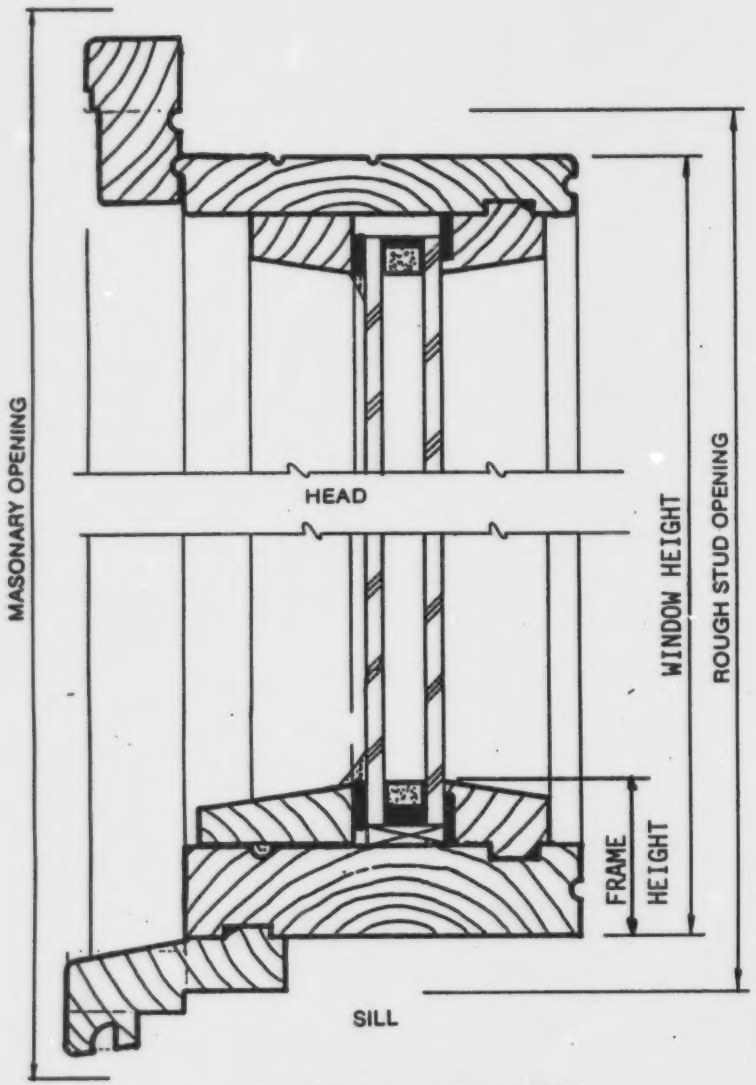
Horizontal Sliding Windows

$$F_{fr} = [(H * (W/2)) - (H - 2 * H_{fr}) * ((W/2) - 2 * H_{fr})] / (H * (W/2)) \quad (9)$$

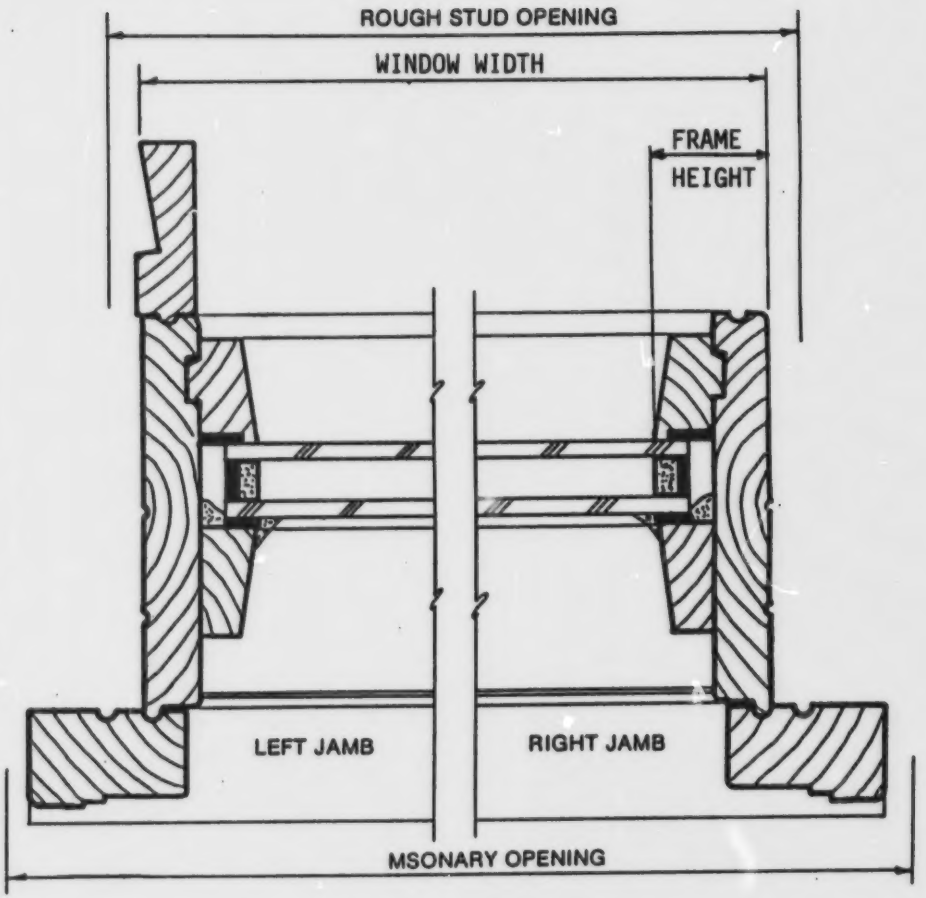
where H is the window height (mm) (see Figure 14)
W is the window width (mm) (see Figure 14)
H_{fr} is the average frame height (mm) (see Figure 14)

This frame height is taken from Tables 8 through 11 for the appropriate frame.

FIGURE 14: WINDOW DIMENSIONS



VERTICAL SECTION



HORIZONTAL SECTION

The fraction centre-of-glass is calculated as follows:

Picture and Hinged Windows

$$F_{cg} = [(H * W) - (H - 127 - 2 * H_{fr}) * (W - 127 - 2 * W_{fr})] / (H * W) \quad (10)$$

Vertical Sliding Windows

$$F_{cg} = [(H/2 * W) - (H/2 - 127 - 2 * H_{fr}) * (W - 127 - 2 * W_{fr})] / (H/2 * W) \quad (11)$$

Horizontal Sliding Windows

$$F_{cg} = [(H * W/2) - (H - 127 - 2 * H_{fr}) * (W/2 - 127 - 2 * W_{fr})] / (H * W/2) \quad (12)$$

where the 127 mm is twice the commonly accepted edge-of-glass height [ASHRAE, 1989].

The fraction edge-of-glass is calculated as follows:

$$F_{eg} = 1 - F_{cg} - F_{fr} \quad (13)$$

5.1.2 Total-Window SHGC

Total-window SHGC at normal incidence angle is calculated as follows:

$$SHGC_{total} = SHGC_{cg} * F_{cg} + SHGC_{eg} * F_{eg} + SHGC_{fr} * F_{fr}$$

where $SHGC_{total}$ = total-window solar heat gain coefficient
$SHGC_{cg}$ = centre-of-glass solar heat gain coefficient
$SHGC_{eg}$ = edge-of-glass solar heat gain coefficient
$SHGC_{fr}$ = frame solar heat gain coefficient

Centre-of-glass SHGC is taken from Table 14 for the appropriate glazing configuration (i.e., number of glazings, pane spacing, coatings, and fill gas).

Edge-of-glass SHGC is equal to the centre-of-glass SHGC.

The frame SHGC is calculated from Equation 5.

$$SHGC_f = 0.015 * a_f * U_f \quad (5)$$

where a_f is the solar absorptivity of the frame (0.9 for dark frames, 0.2 for white frames)

U_f is the frame heat loss coefficient in W/(m²*C).

5.2 Example Calculations

5.2.1 Example One

This example will calculate the U-value and SHGC for a double-glazing with one low-emissivity coating (e = 0.09), an argon fill gas, an insulating spacer and a 13 mm pane spacing in a wood casement frame. The window is 600 mm wide and 1200 mm high.

Centre-of-Glass U-Value

Glazing System- Double Glass
- One Low-e (e = 0.09) Coating
- 13 mm pane spacing
- argon gas

From Table 5 U_{cg} = 1.56 W/(m²*C)

Edge-of-Glass U-Value

Spacer Type - One Insulating Spacer

From Table 6
A = 0.681
B = 0.682
C = 0.043
U_{eg} = 1.85 W/(m²*C)

Frame U-Value

Frame - Wood Casement
- Insulating Spacer

From Table 9 U_{fr} = 2.09 W/(m²•C) and H_{fr} = 78.1 mm

Centre-of-Glass SHGC

From Table 14 $SHGC_{cg}$ = 0.64

The balance of the calculations are included in Figure 15. The total-window U-value for this window is 1.82 W/(m²•C) and the SHGC is 0.42.

5.2.2. Example 2

This example will calculate the U-value and SHGC for a triple glazing with two low emissivity coatings (e = 0.20), with argon gas, one insulating and one metal spacer, and 13 mm pane spacing in an aluminum-clad wood double-hung (vertical sliding) frame. The window is 900 mm wide and 1500 mm high.

Centre-of-glazing U-value

Glazing System - Triple Glass
- Two Low-e (e = 0.20) coatings
- 13 mm pane spacings
- argon gas

From Table 5 U_{cg} = 0.96 W/(m²•C)

Edge-of-Glass U-Value

Spacer Type - one insulating, one metal

Figure 15 Example Calculation 1
TOTAL WINDOW U-VALUE and SHGC CALCULATION SHEET

STEP 1 WINDOW U-VALUE

I Centre of Glass U-value from Table 5

Centre of Glass U-value — 1.56

II Edge of Glass U-value Constants from Table 6

A = 0.681, B = 0.683, C = 0.043

$U_{eg} = A + B * U_{cg} + C * U_{cg}^2$ = 1.85

III Frame U-value from Tables 8 through 11

Metal Spacer		
Insulating Spacer		2.09
Glass Spacer	$0.50 * U_{metal} + 0.50 * U_{insul}$ =	
Metal + Insul. Spacer	$0.15 * U_{metal} + 0.85 * U_{insul}$ =	

IV Component Fractions

Frame Height and Window Width and Height [mm]

Window Width, W = 600, Height, H = 1200

Frame Height = 78.1, from Tables 8 through 11

Fraction Frame

Picture and Hinged Windows

$F_{fr} = [(W * H) - (W - 2 * H_{fr}) * (H - 2 * H_{fr})] / (W * H)$ — 0.36

Vertical Sliding Windows

$F_{fr} = [(W * (H/2)) - (W - 2 * H_{fr}) * ((H/2) - 2 * H_{fr})] / (W * (H/2))$ —

Horizontal Sliding Windows

$F_{fr} = [((W/2) * H) - ((W/2) - 2 * H_{fr}) * (H - 2 * H_{fr})] / ((W/2) * H)$ —

Fraction Centre of Glass

Picture and Hinged Windows

$F_{cg} = [(W - 2 * H_{fr} - 127) * (H - 2 * H_{fr} - 127)] / (W * H)$ — 0.40

Vertical Sliding Windows

$F_{cg} = [(W - 2 * H_{fr} - 127) * ((H/2) - 2 * H_{fr} - 127)] / (W * (H/2))$ —

Horizontal Sliding Windows

$F_{cg} = [((W/2) - 2 * H_{fr} - 127) * (H - 2 * H_{fr} - 127)] / ((W/2) * H)$ —

Fraction Edge of Glass

$F_{eg} = 1 - F_{cg} - F_{fr}$ — 0.24

V Window U-value

$U_{total} = U_{cg} * F_{cg} + U_{eg} * F_{eg} + U_{fr} * F_{fr}$ — 1.82

STEP 2 SHGC CALCULATION

I Centre of Glass SHGC from Table 14

$SHGC_{cg}$ — 0.64

II Frame SHGC

$SHGC_{fr} = 0.015 * 0.9 * U_{fr}$ = — 0.03

III Window SHGC

$SHGC_{total} = SHGC_{cg} * (F_{cg} + F_{eg}) + SHGC_{fr} * F_{fr}$ = — 0.42

From Table 6

$A = 0.769$

$B = 0.706$

$C = 0.033$

$U_{cg} = 1.48$

Frame U-Value

Frame

- aluminum clad wood, vertical sliding
- one insulating and one metal spacer

From Table 10

U_{fr} (metal) = 3.25 W/(m^2*C)

U_{fr} (insulating) = 2.65 W/(m^2*C)

$U_{fr} = 0.15 * (3.25) + 0.85 * (2.65) = 2.74$ W/(m^2*C)

$H_{fr} = 58.4$ mm

Centre-of-Glass SHGC

From Table 14

$SHGC_{cg} = 0.66$

The balance of the calculations are included in Figure 16. The total window U-value for this window is 1.57 W/(m^2*C) and the SHGC is 0.49.

Figure 16 Example Calculation 2
TOTAL WINDOW U-VALUE and SHGC CALCULATION SHEET

STEP 1 WINDOW U-VALUE

I Centre of Glass U-value from Table 5

Centre of Glass U-value — 0.96

II Edge of Glass U-value Constants from Table 6

A = 0.769, B = 0.706, C = 0.033

$U_{eg} = A + B * U_{cg} + C * U_{cg}^2$ = 1.48

III Frame U-value from Tables 8 through 11

Metal Spacer	U_{metal} = 3.25	
Insulating Spacer	U_{insul} = 2.65	
Glass Spacer	$0.50 * U_{metal} + 0.50 * U_{insul}$ =	
Metal + Insul. Spacer	$0.15 * U_{metal} + 0.85 * U_{insul}$ =	2.74

IV Component Fractions

Frame Height and Window Width and Height [mm]

Window Width, W = 900, Height, H = 1500

Frame Height = 58.4, from Tables 8 through 11

Fraction Frame

Picture and Hinged Windows

$F_f = [(W * H) - (W - 2 * H_f) * (H - 2 * H_f)] / (W * H)$

Vertical Sliding Windows

$F_f = [(W * (H/2)) - (W - 2 * H_f) * ((H/2) - 2 * H_f)] / (W * (H/2))$ — 0.27

Horizontal Sliding Windows

$F_f = [((W/2) * H) - ((W/2) - 2 * H_f) * (H - 2 * H_f)] / ((W/2) * H)$

Fraction Centre of Glass

Picture and Hinged Windows

$F_{cg} = [(W - 2 * H_f - 127) * (H - 2 * H_f - 127)] / (W * H)$

Vertical Sliding Windows

$F_{cg} = [(W - 2 * H_f - 127) * ((H/2) - 2 * H_f - 127)] / (W * (H/2))$ — 0.49

Horizontal Sliding Windows

$F_{cg} = [((W/2) - 2 * H_f - 127) * (H - 2 * H_f - 127)] / ((W/2) * H)$

Fraction Edge of Glass

$F_{eg} = 1 - F_{cg} - F_f$ — 0.24

V Window U-value

$U_{total} = U_{cg} * F_{cg} + U_{eg} * F_{eg} + U_f * F_f$ — 1.57

STEP 2 SHGC CALCULATION

I Centre of Glass SHGC from Table 14

$SHGC_{cg}$ — 0.66

II Frame SHGC

$SHGC_f = 0.015 * 0.9 * U_f$ = 0.04

III Window SHGC

$SHGC_{total} = SHGC_{cg} * (F_{cg} + F_{eg}) + SHGC_f * F_f$ = 0.49

6. CONCLUSIONS AND RECOMMENDATIONS

6.1 Conclusions

Based on the work contained in this report, the following conclusions can be made.

The average difference between VISION/FRAME-simulated and NRC-tested total-window U-values was 2.4% for the 13 windows studied. The FRAME program predictions for frame and edge heat loss are all within the uncertainty of the NRC test results. As a result, the FRAME program appears to provide reasonable estimates of frame and edge heat loss.

Heat loss from most window frames can be divided into representative categories if normalized by the projected area. Frame U-values for all aluminum windows are more dependent on the surface area than on projected area but should be based on projected area for consistency.

Aluminum and thermally-broken aluminum frames, in general, have higher heat loss coefficients than do wood, vinyl and fibreglass frames. Semi-sashless slider and hinged frame U-values are usually lower than those of slider and picture frames. The type of spacer used in the sealed glazing unit has a significant effect on frame heat loss.

The variation in centre-of-glass SHGC as a function of the outdoor temperature, solar radiation level, and outside film coefficient was less than one percent for a wide range in each parameter. As such, any set of standard conditions can be selected for residential window energy evaluation.

SHGC is a function of incidence angle; however, the variation between most glazing types is small for incidence angles of practical interest. A simple equation can be used to calculate an off-normal incidence factor, where required, regardless of glazing type.

The frame and edge-of-glass heat transfer has little effect on the SHGC for windows with wooden frames. The effect of the frame and edge-of-glass on the SHGC for windows with aluminum or thermally-broken aluminum frames is less than five percent. A simple equation can be used to calculate frame SHGC as a function of frame U-value.

6.2 Recommendations

Recommendations arising as a result of this report are:

- further validation of the FRAME program's U-value predictions is required especially for frame types not already examined (e.g., a wider range of sliders and semi-sashless sliders). (Note: plans are already in hand to look at more windows as a part of the joint Canada-U.S. research project.)

- work is needed to determine how the frame U-values presented in this report could be used in a window performance labelling program (i.e., how to interpolate and extrapolate the results to other frame types).

- the calculation method for total window SHGC should be compared to experimental results, when these become available.

7. REFERENCES

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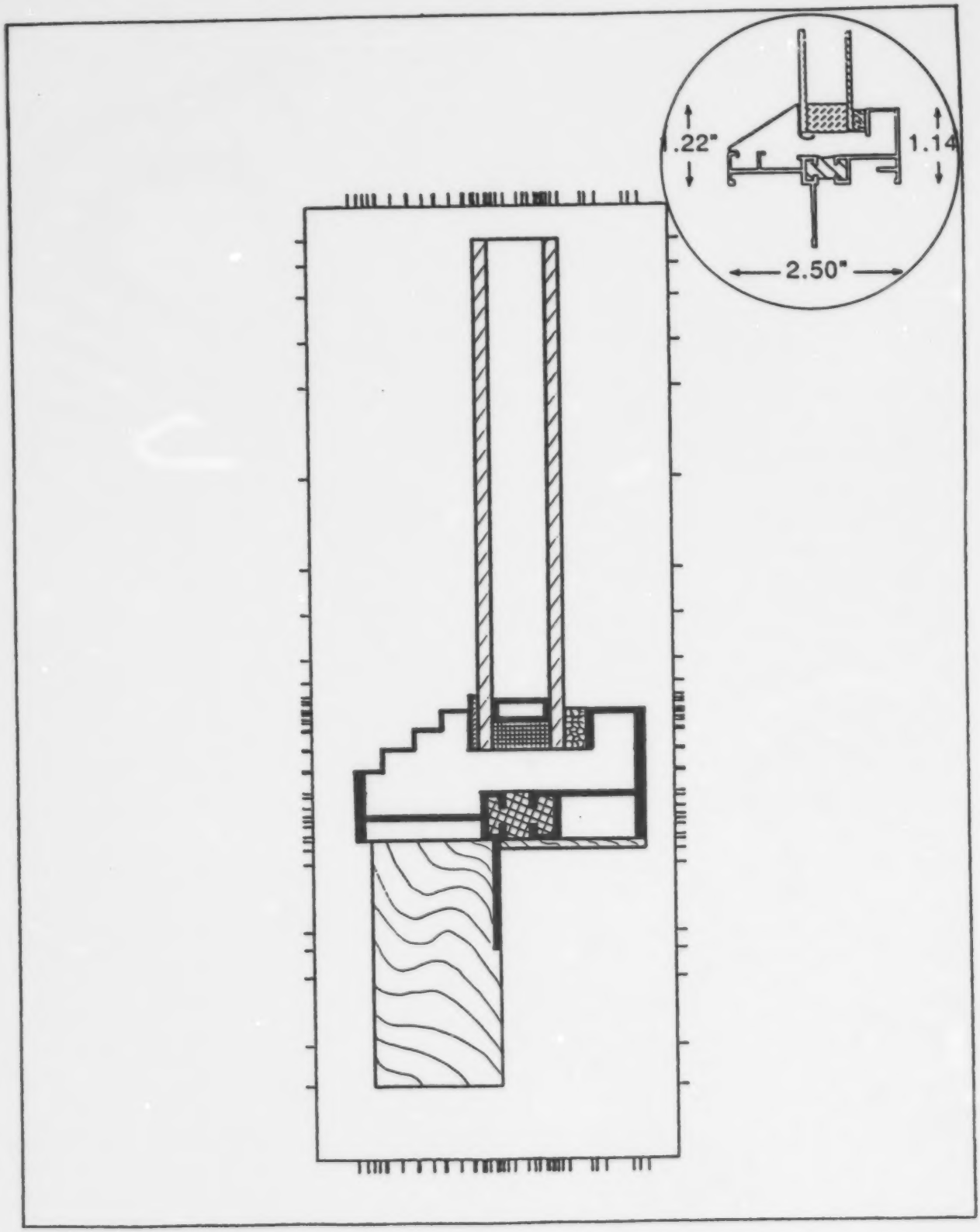
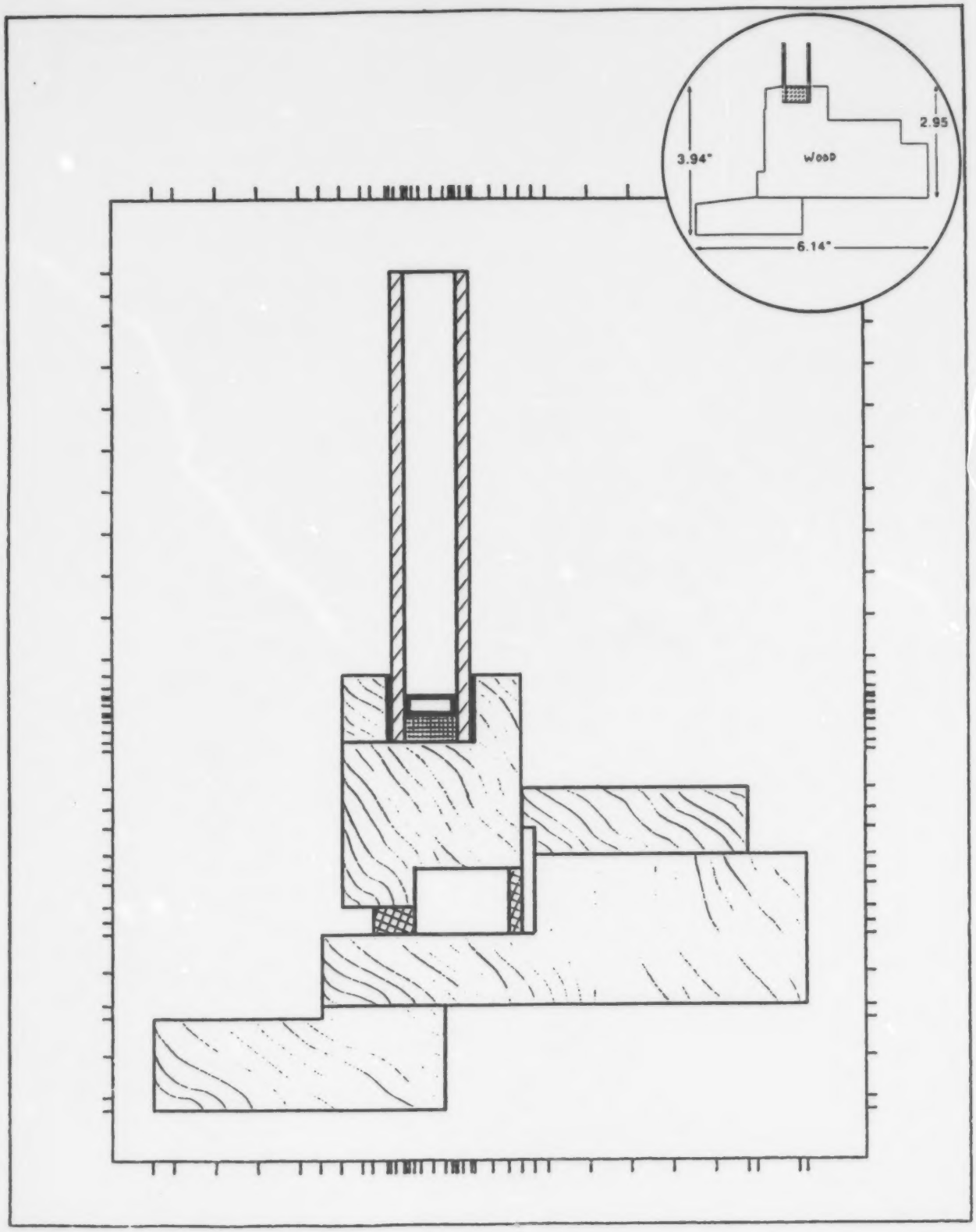
APPENDIX A: WINDOW CROSS-SECTIONS USED IN JOINT CANADA/U.S. RESEARCH PROJECT

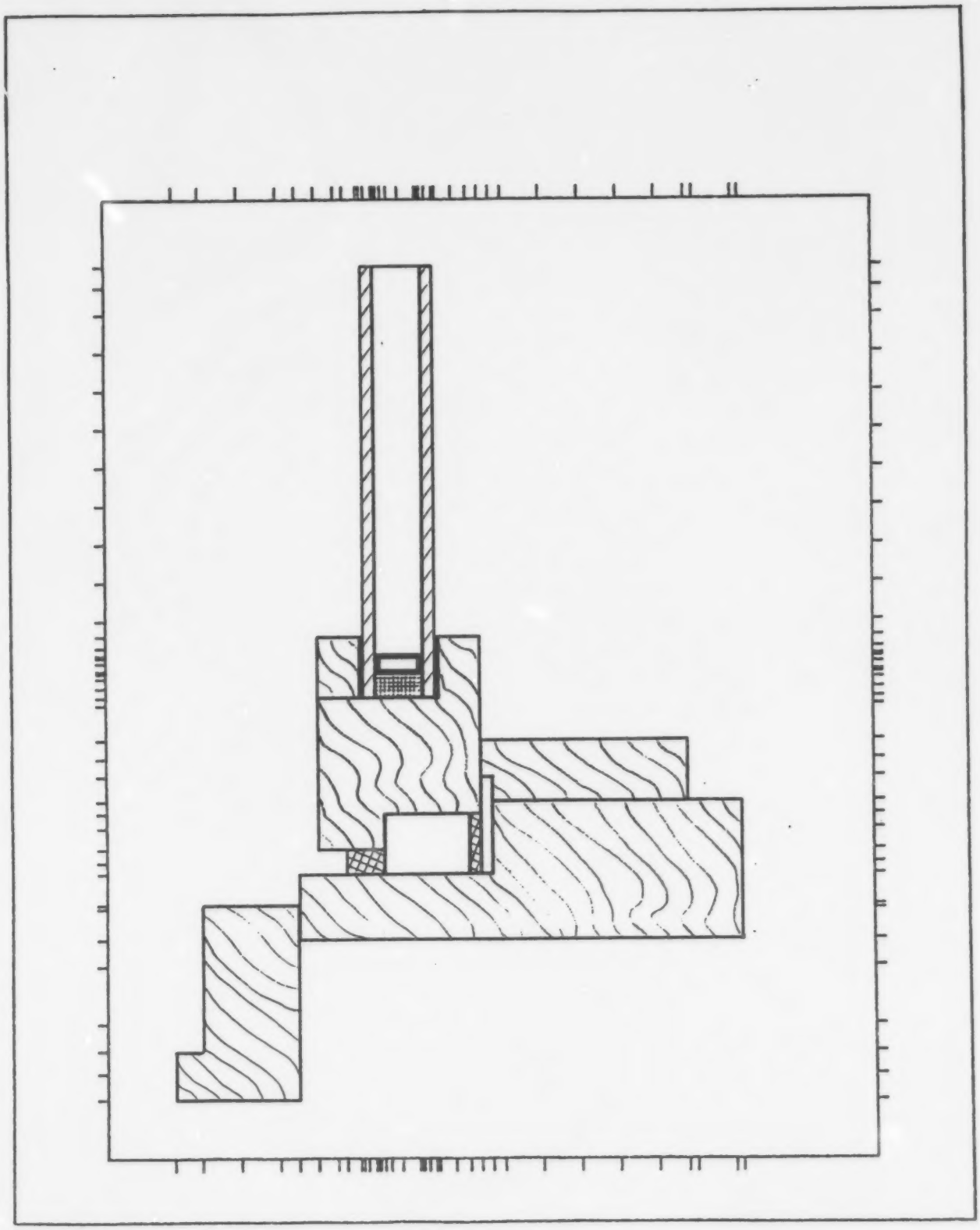
FRAME REPRESENTATION FOR WINDOW #1



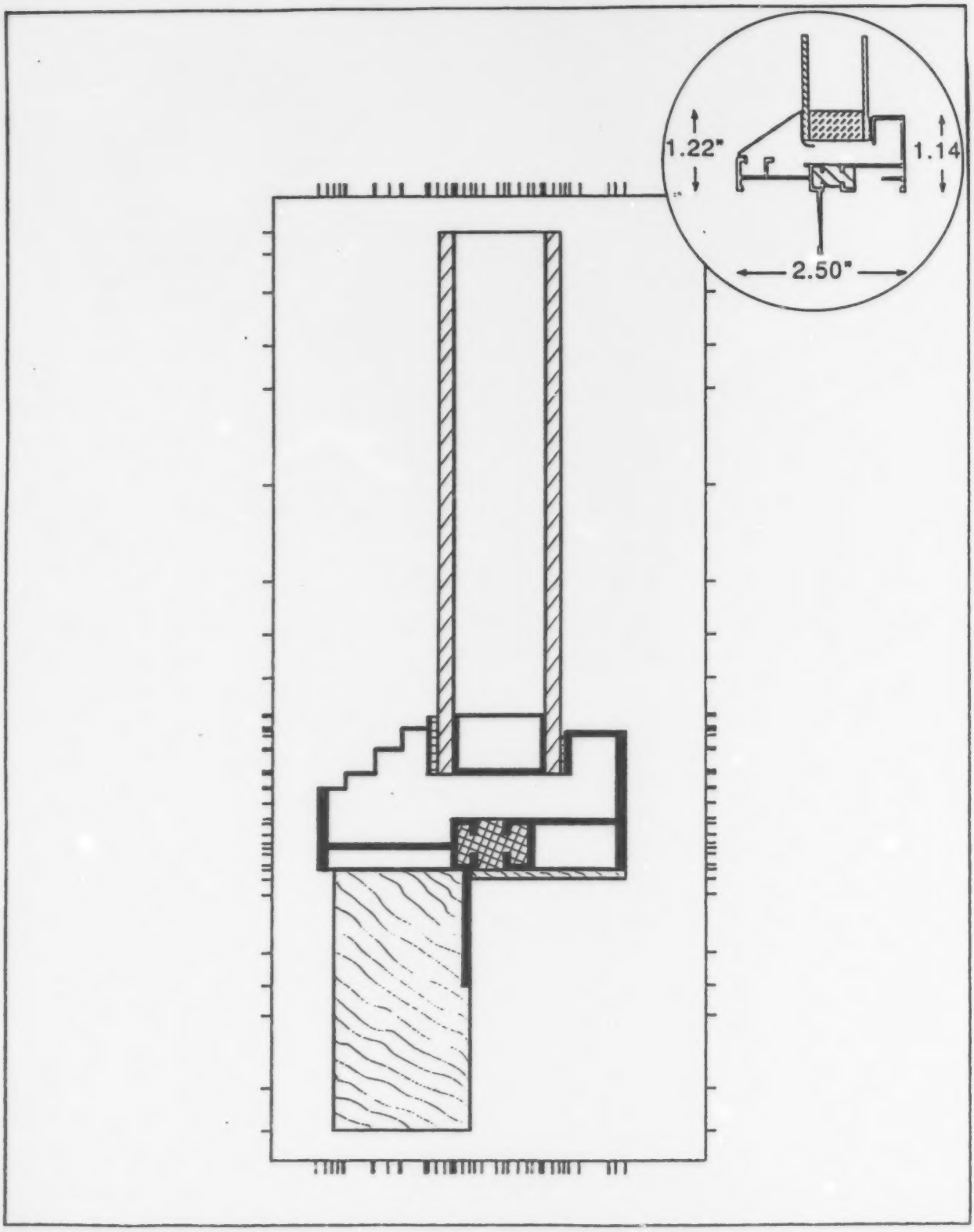
FRAME REPRESENTATION FOR WINDOW #2 (SILL)



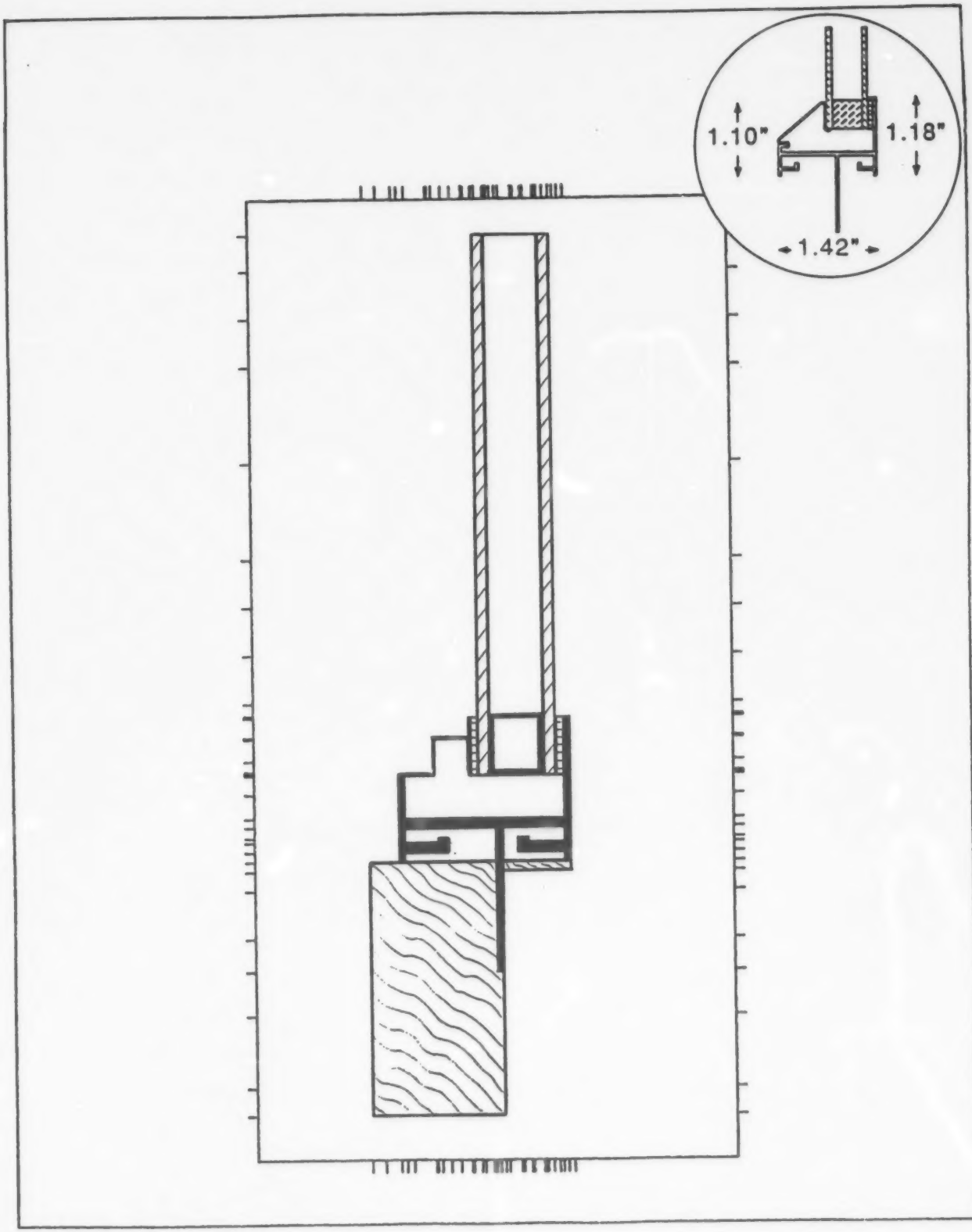
FRAME REPRESENTATION FOR WINDOW #2 (HEAD/JAMB)



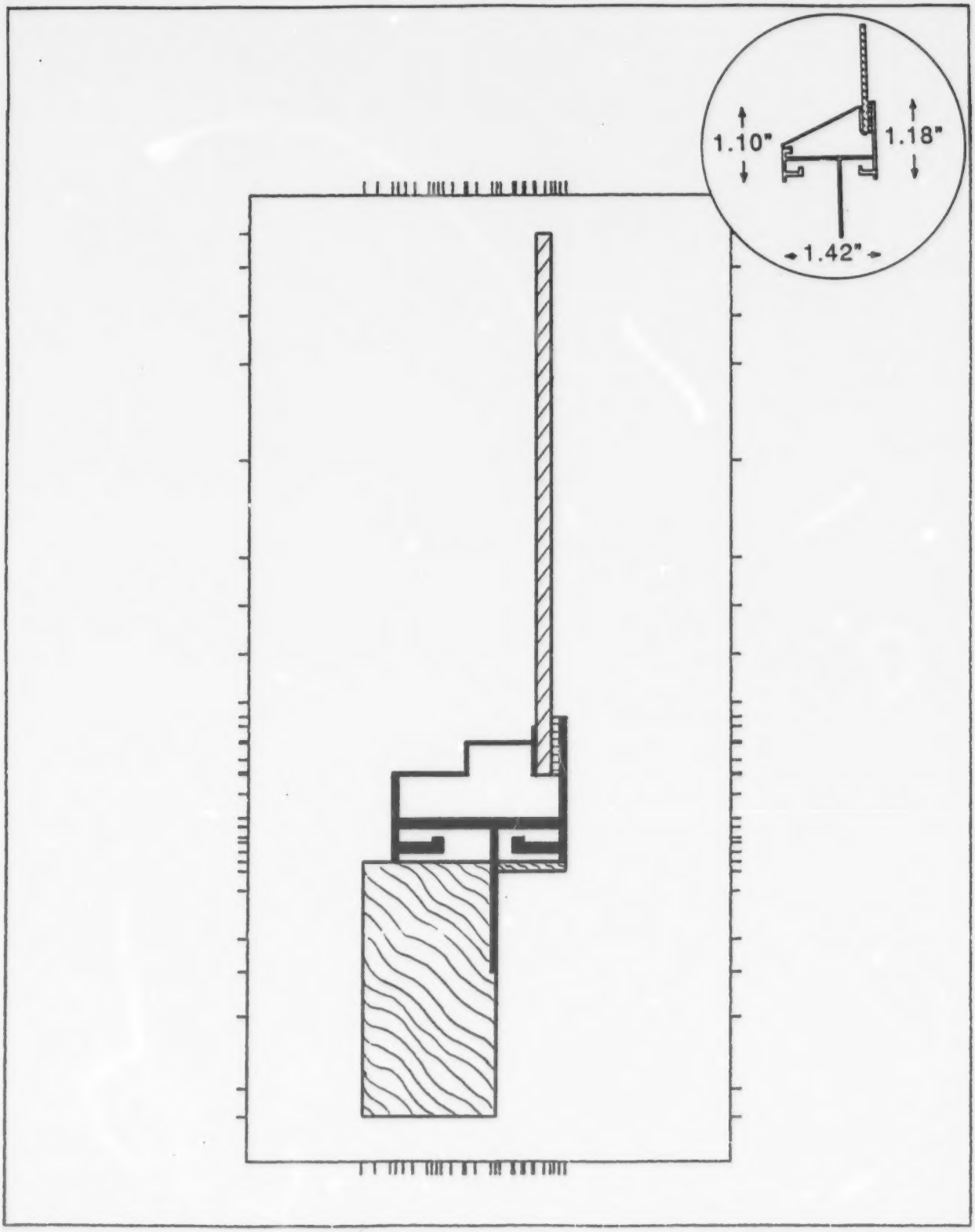
FRAME REPRESENTATION FOR WINDOW #3



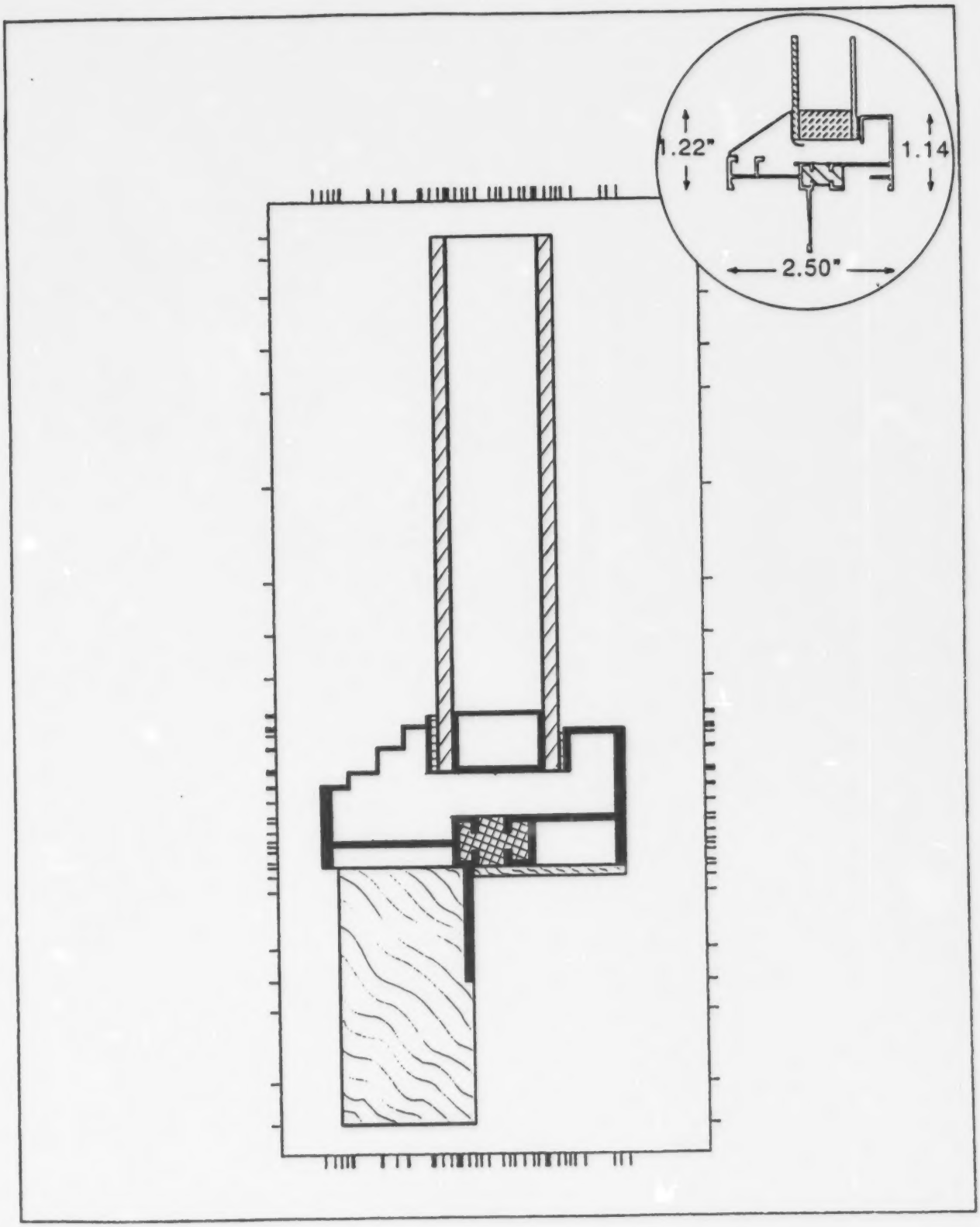
FRAME REPRESENTATION FOR WINDOW #4



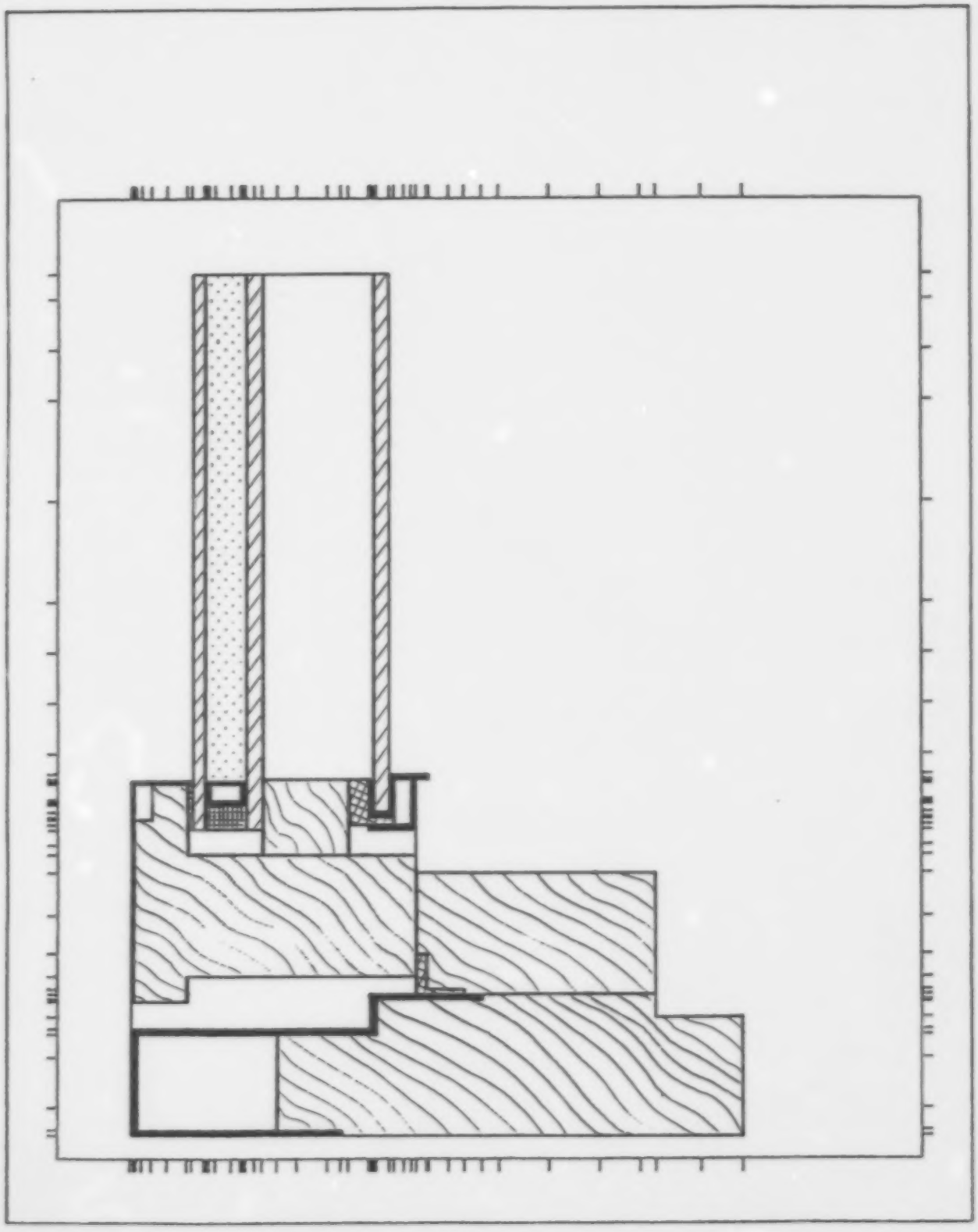
FRAME REPRESENTATION FOR WINDOW #5



FRAME REPRESENTATION FOR WINDOW #6



FRAME REPRESENTATION FOR WINDOW #7

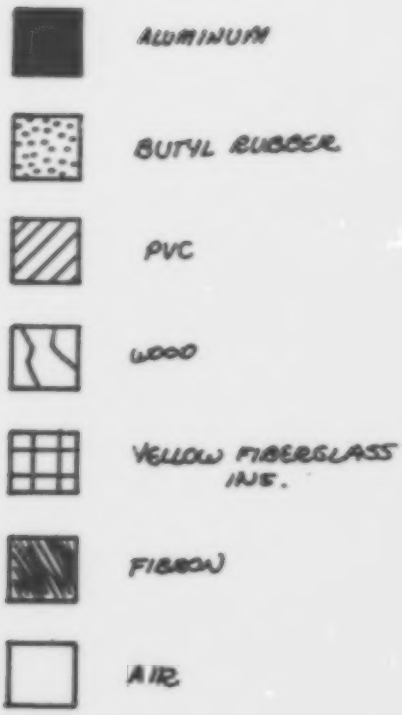


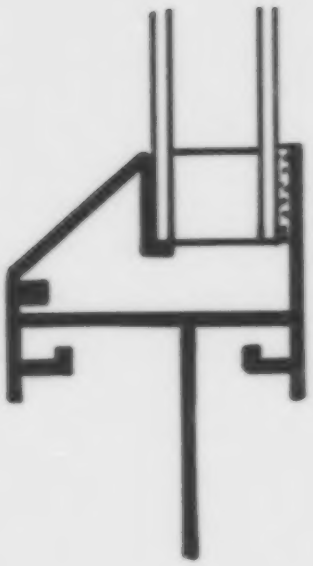
APPENDIX B.1: PICTURE WINDOW CROSS-SECTIONS

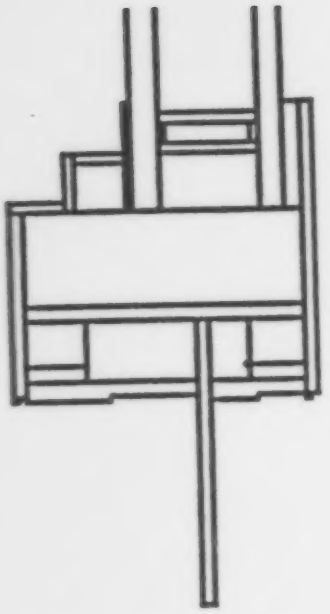
Notes:

1) Actual Cross-Section on left, FRAME Program representation on right.

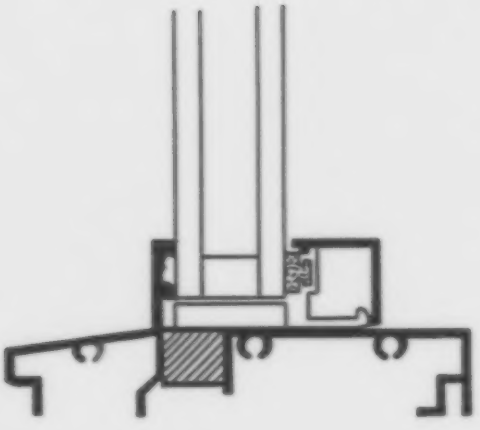
2) Material Legend:

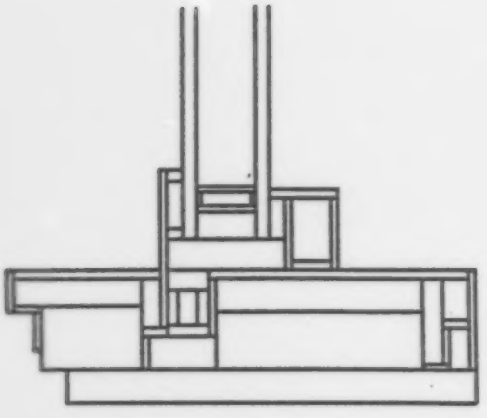






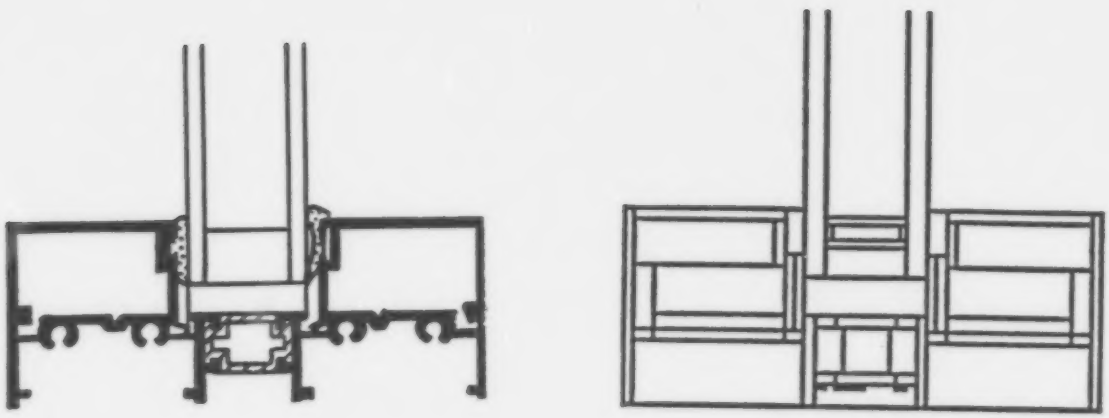
Aluminum Picture Frame - P1



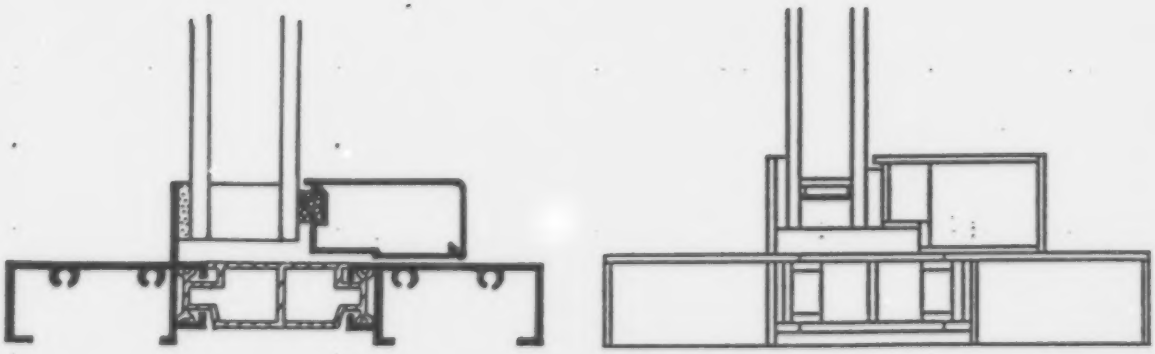


Aluminum Picture Frame with 5mm Thermal Break - P3

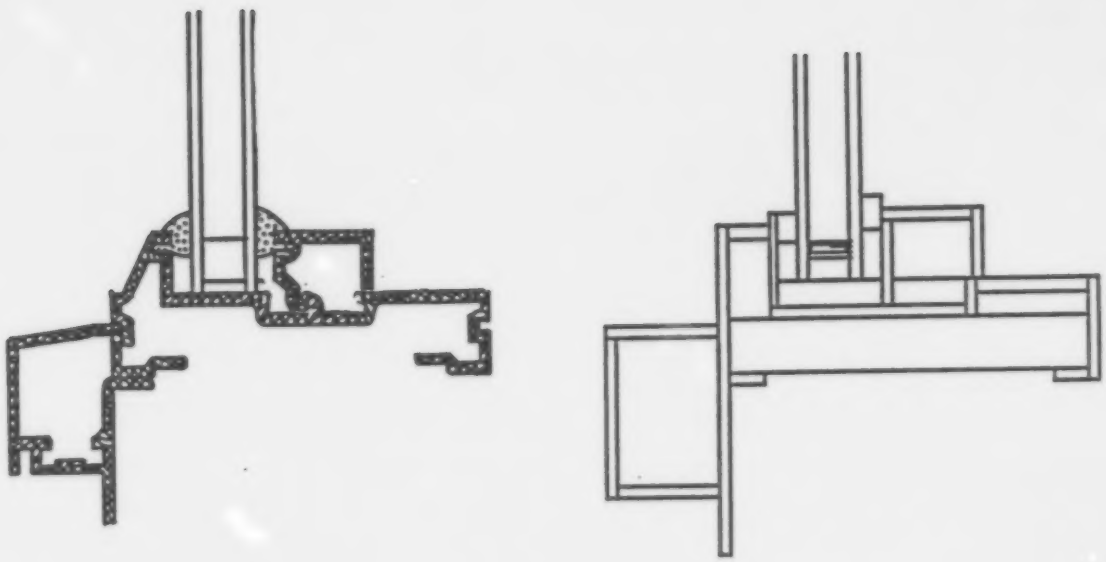
Aluminum Picture Frame with Thermal Break Removed - P2



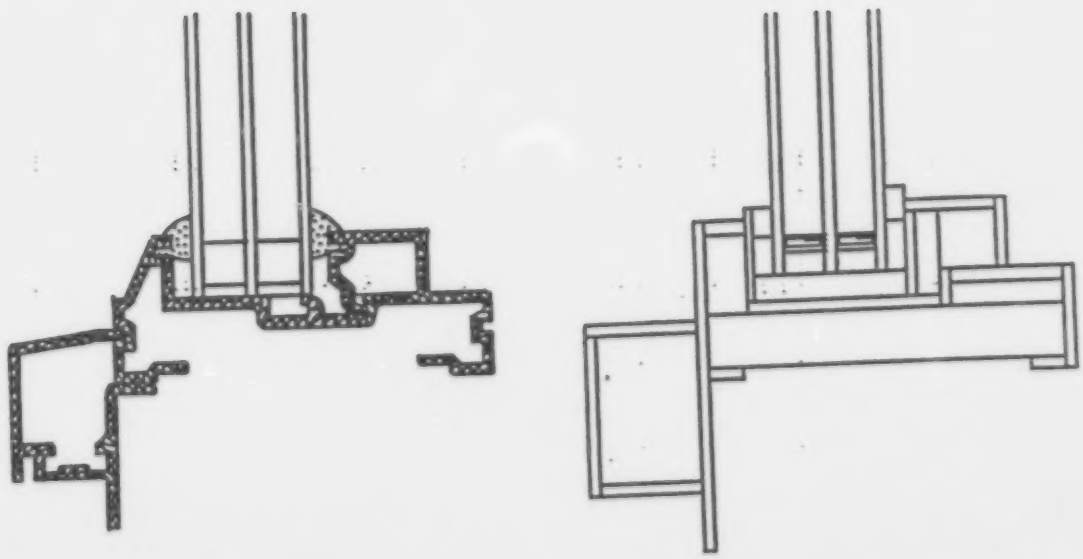
Aluminum Picture Frame with 9mm Thermal Break - P4



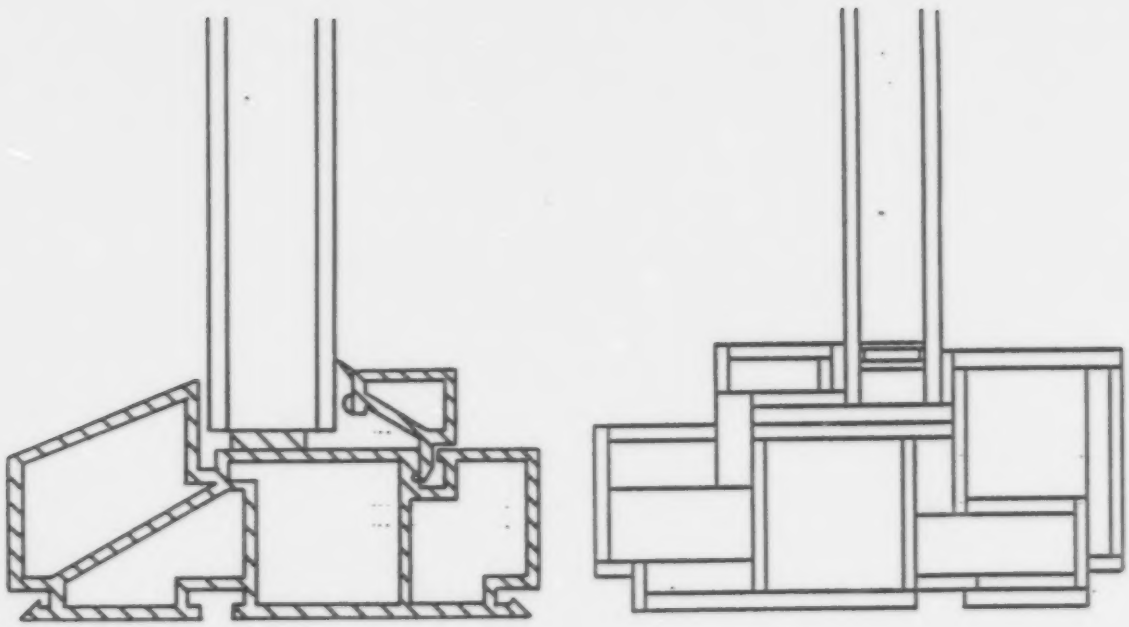
Aluminum Picture Frame with 33mm Thermal Break - P5



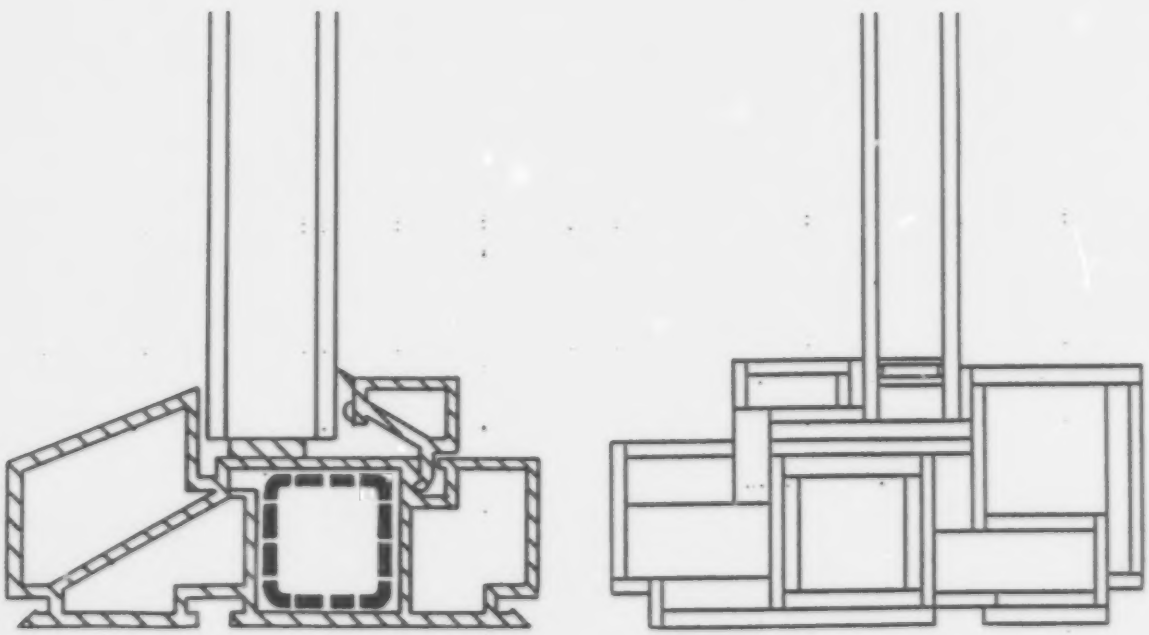
Fibreglass Picture Frame: Double-Glazed - P6



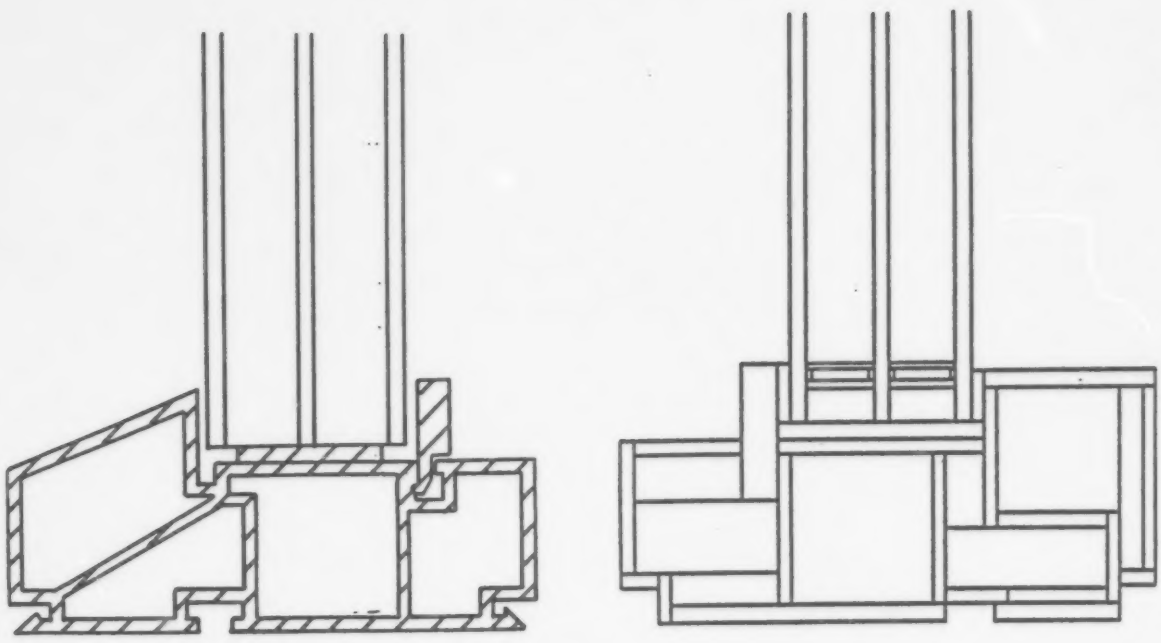
Fibreglass Picture Frame: Triple-Glazed - P7



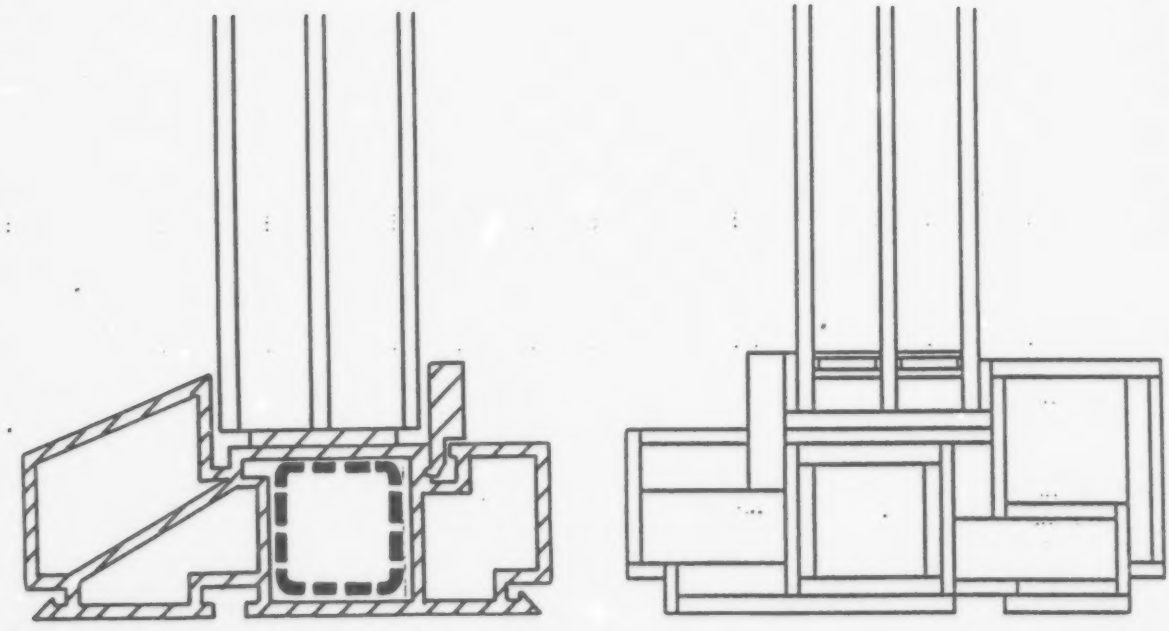
Vinyl Picture Frame: Double-Glazed - P8



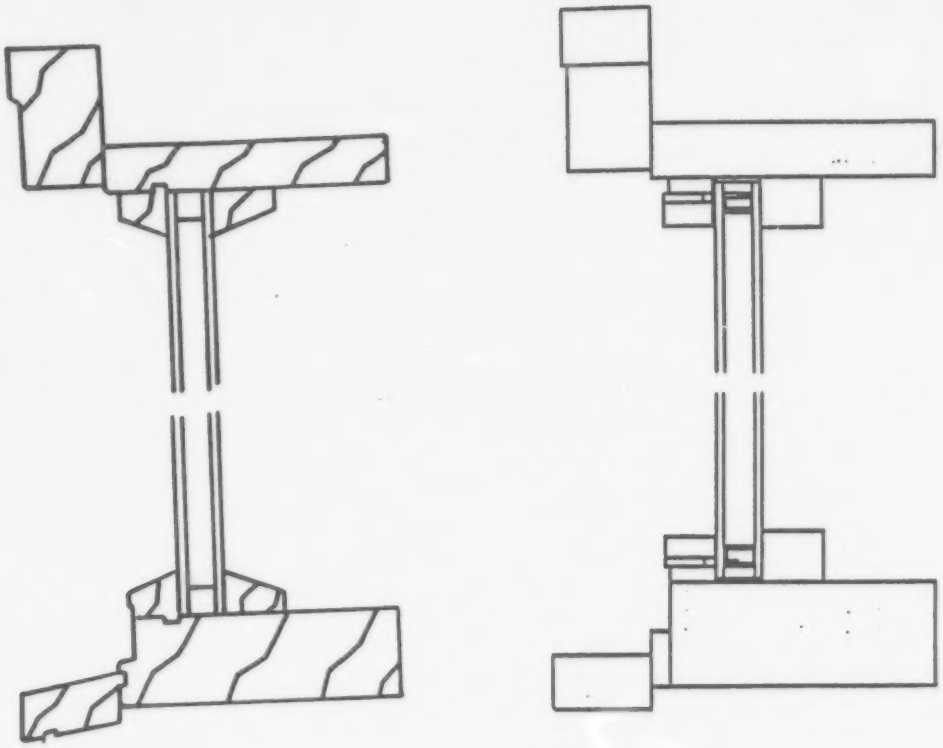
Reinforced Vinyl Picture Frame: Double-Glazed - P10



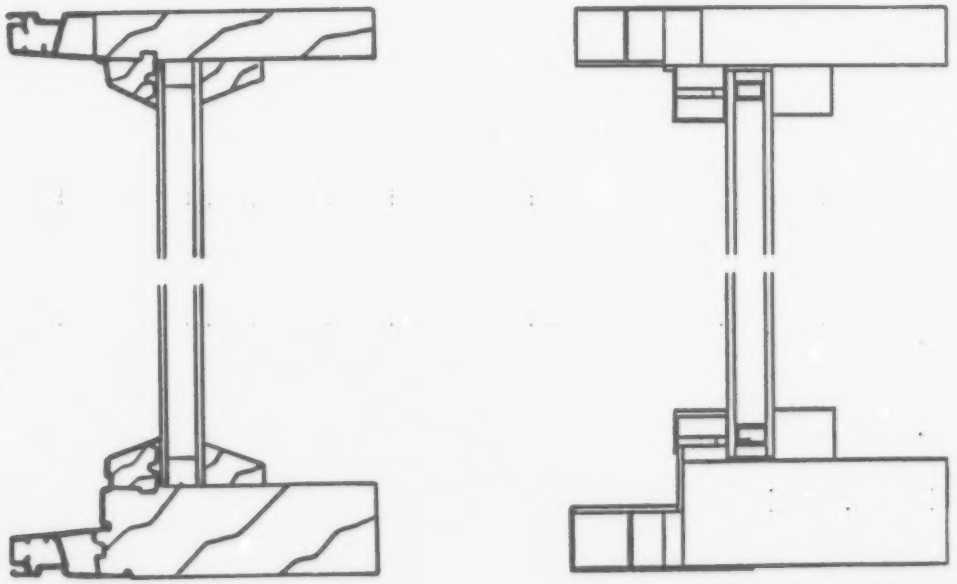
Vinyl Picture Frame: Triple-Glazed - P9



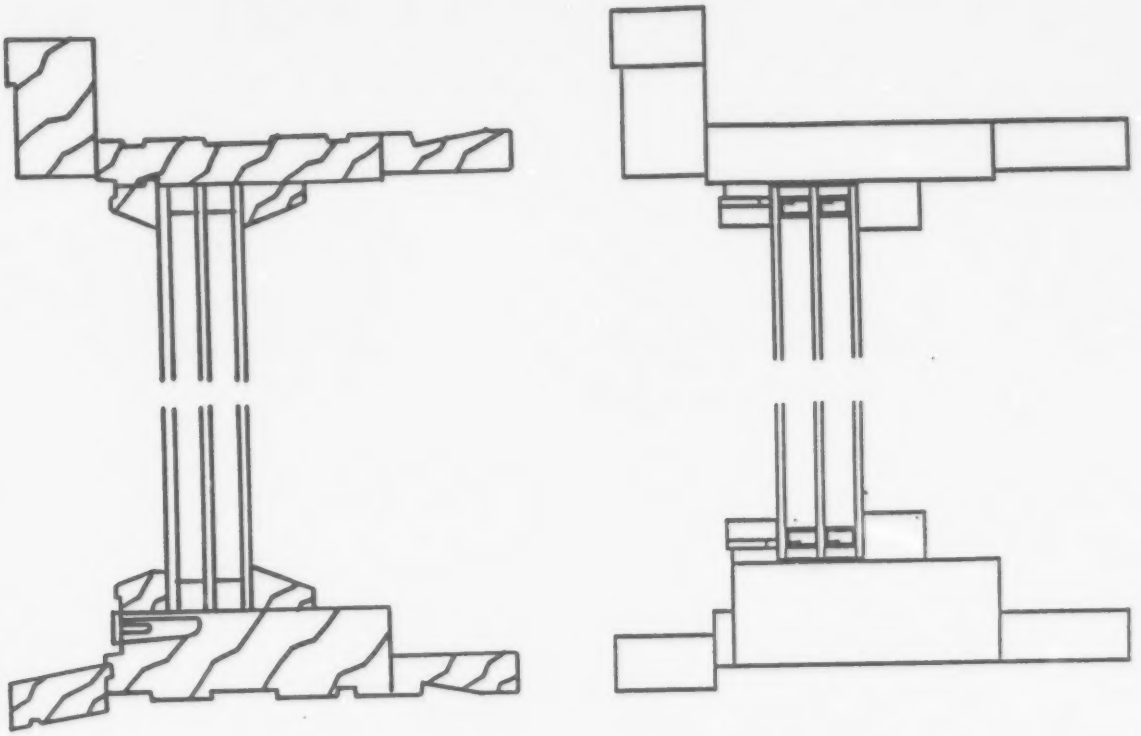
Reinforced Vinyl Picture Frame: Triple-Glazed - P11



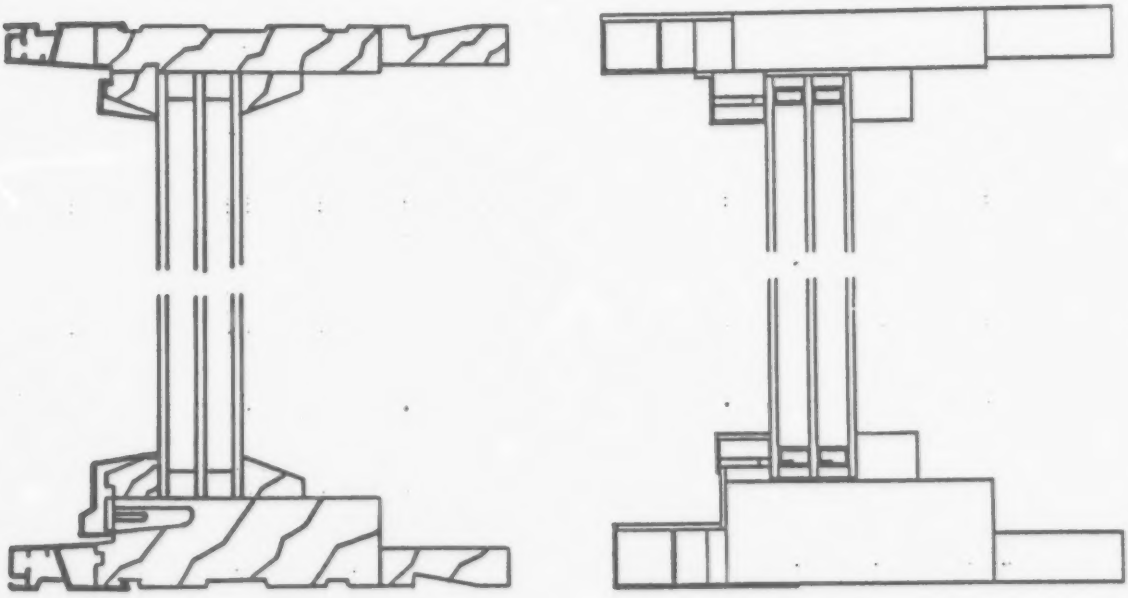
Wood Picture Frame: Double-Glazed - P12



Aluminum-Clad Wood Picture Frame: Double-Glazed - P13



Wood Picture Frame: Triple-Glazed - P14



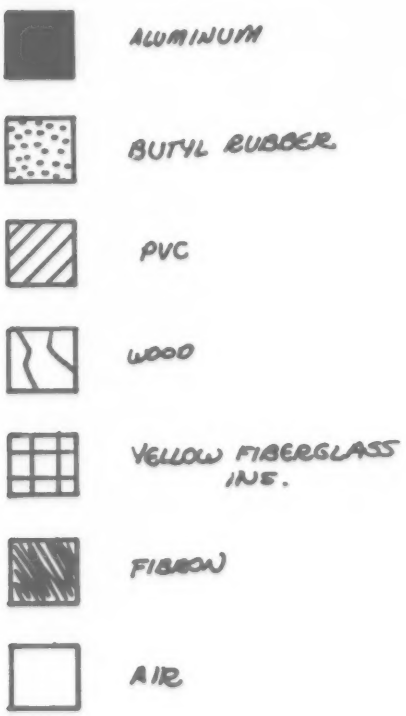
Aluminum-Clad Wood Picture Frame: Triple-Glazed - P15

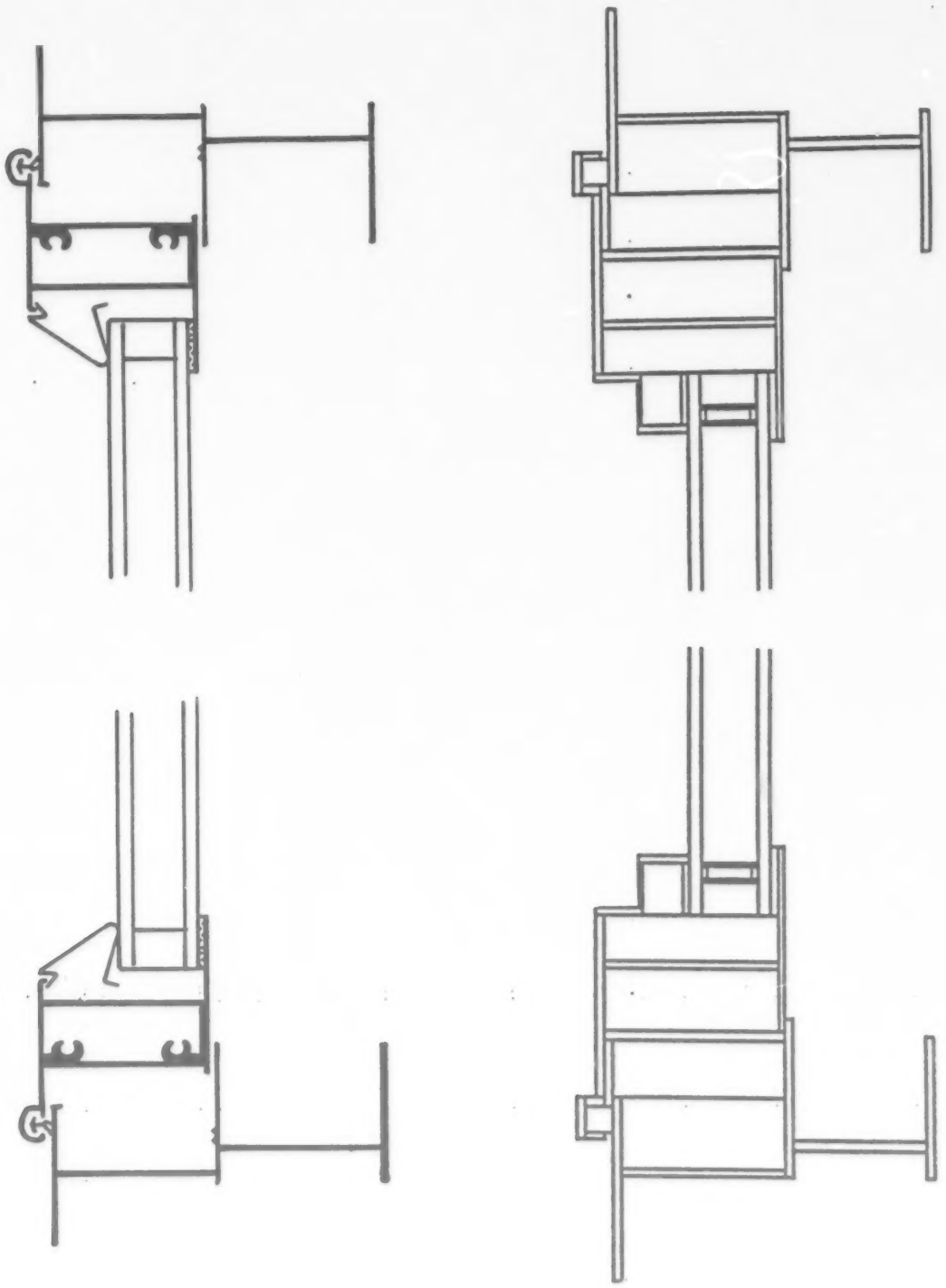
APPENDIX B.2: HINGED WINDOW CROSS-SECTIONS

Notes:

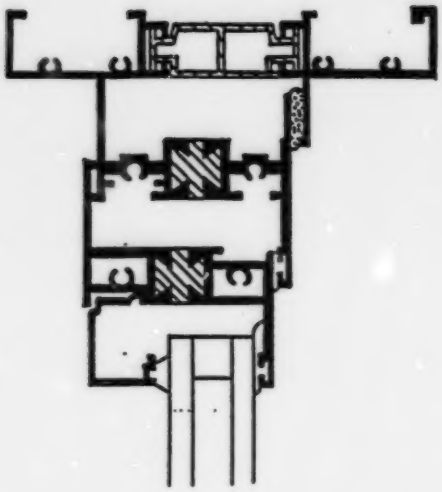
1) Actual Cross-Section on left, FRAME Program representation on right.

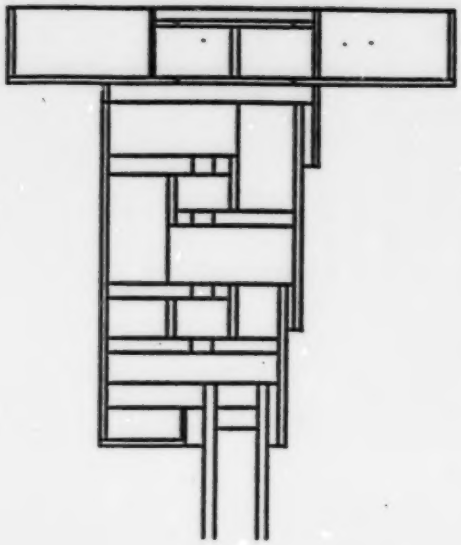
2) Material Legend:

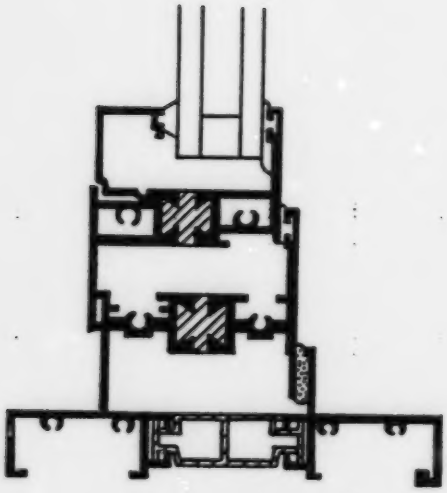


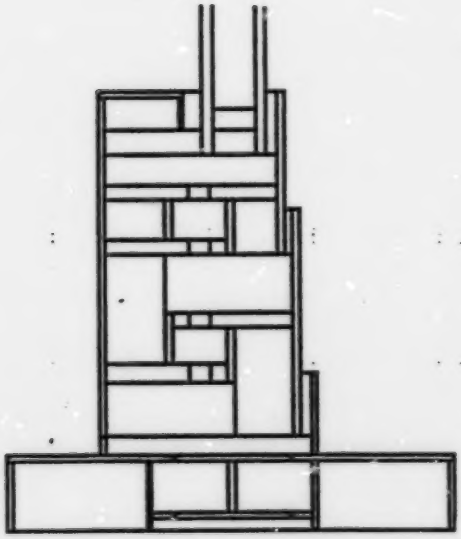


Aluminum Hinged Frame - H1

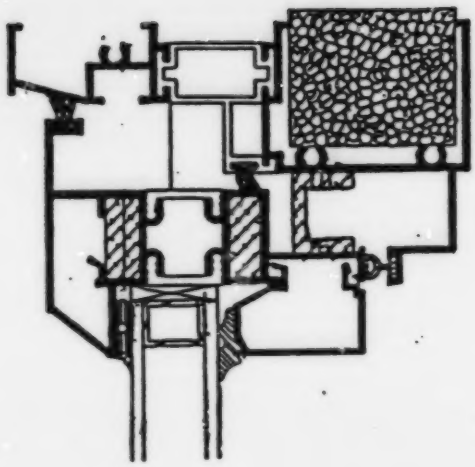


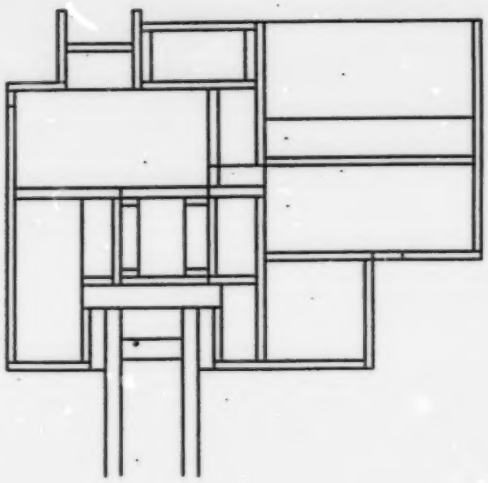


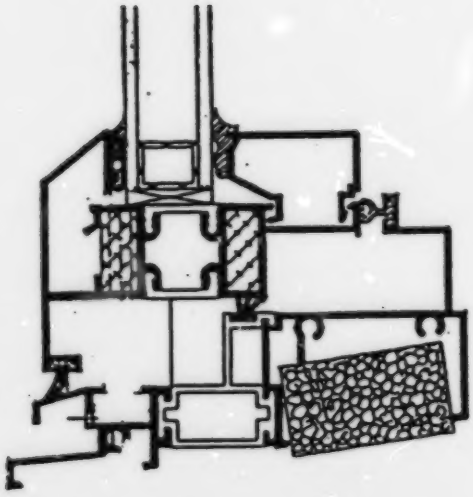


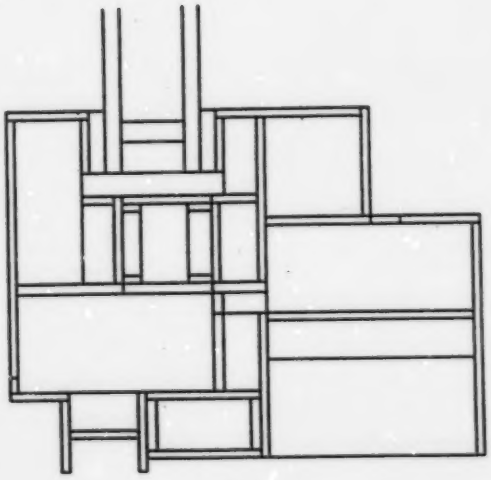


Aluminum Hinged Frame with 5mm Thermal Break - H2

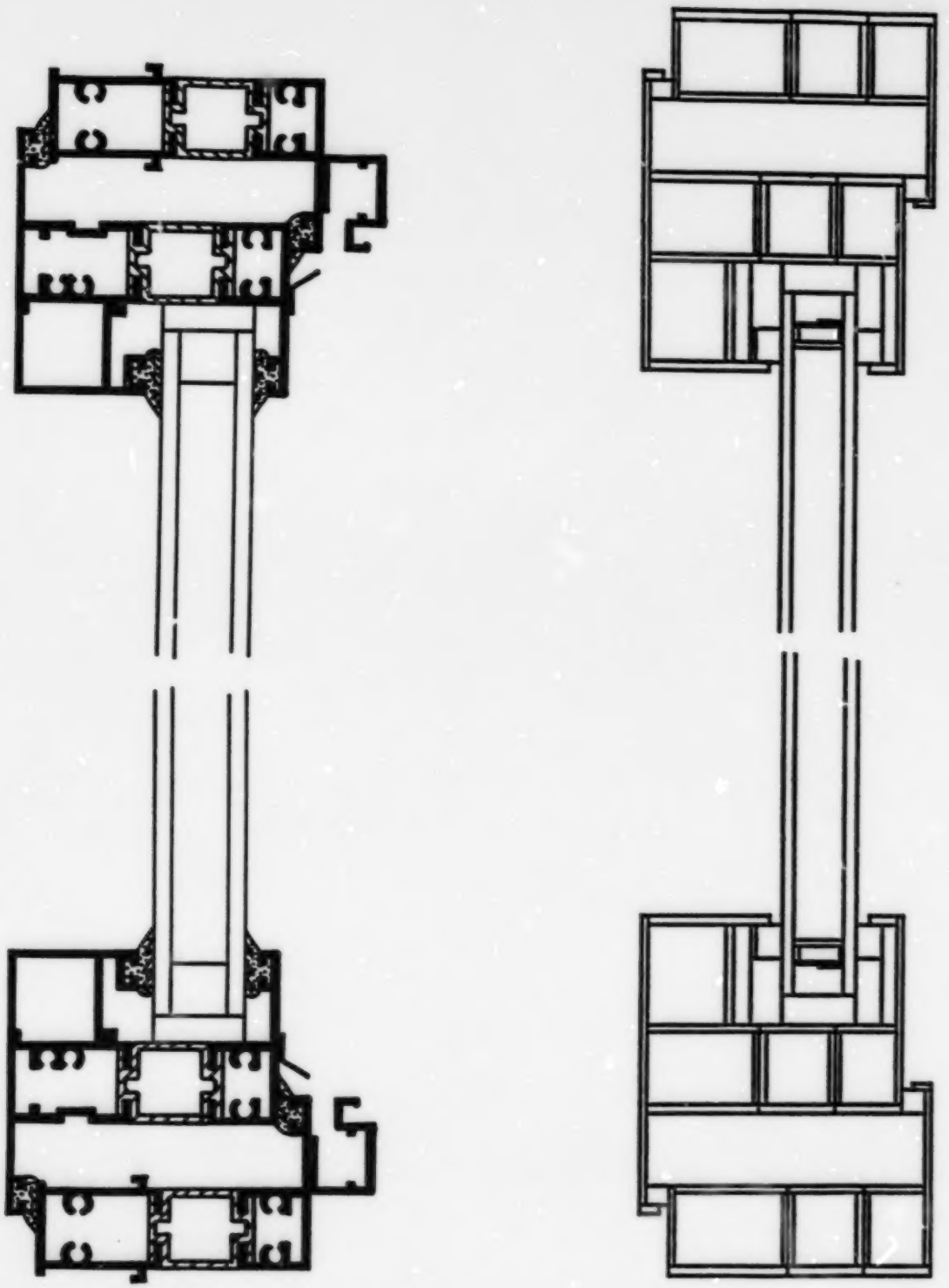




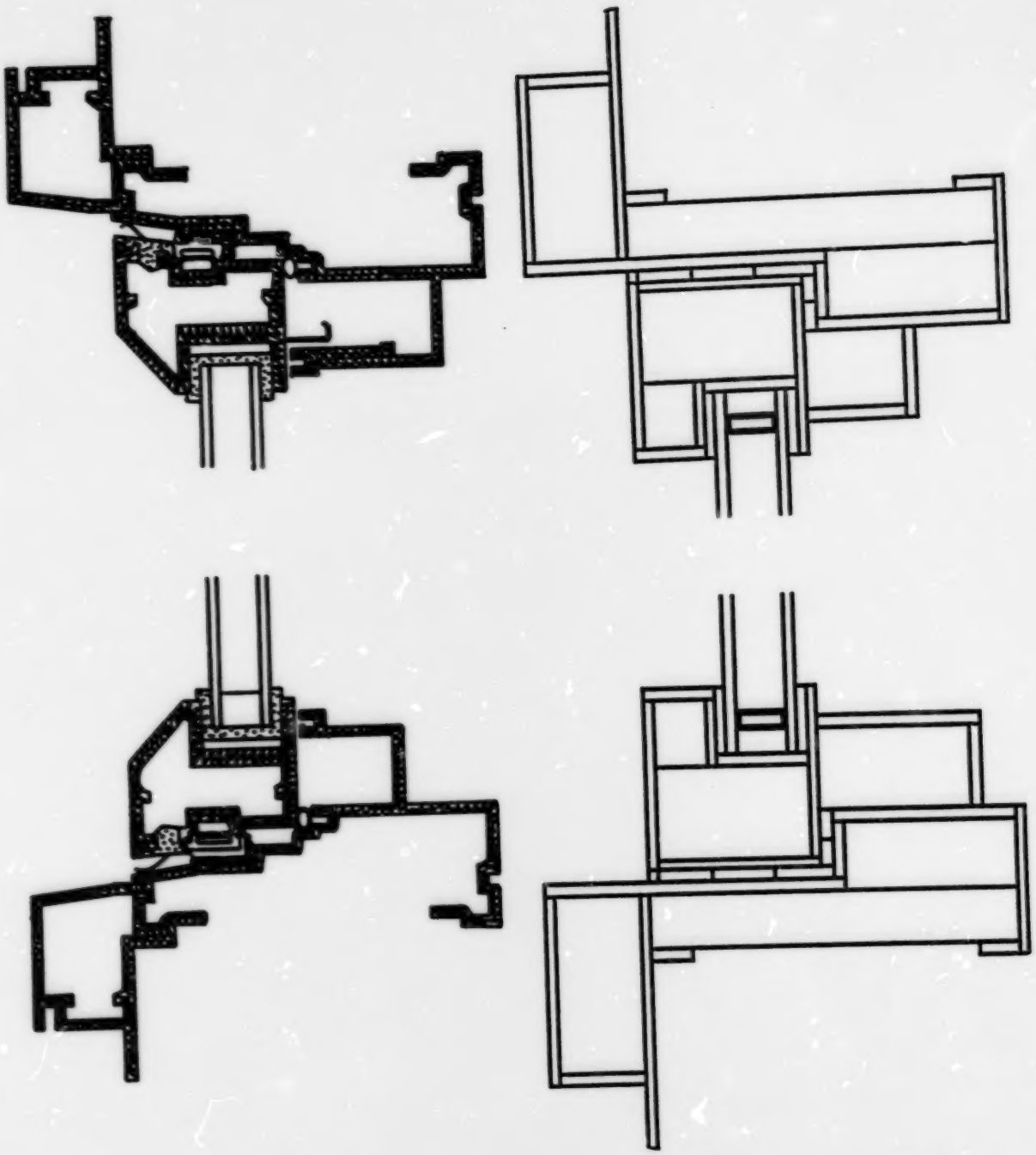




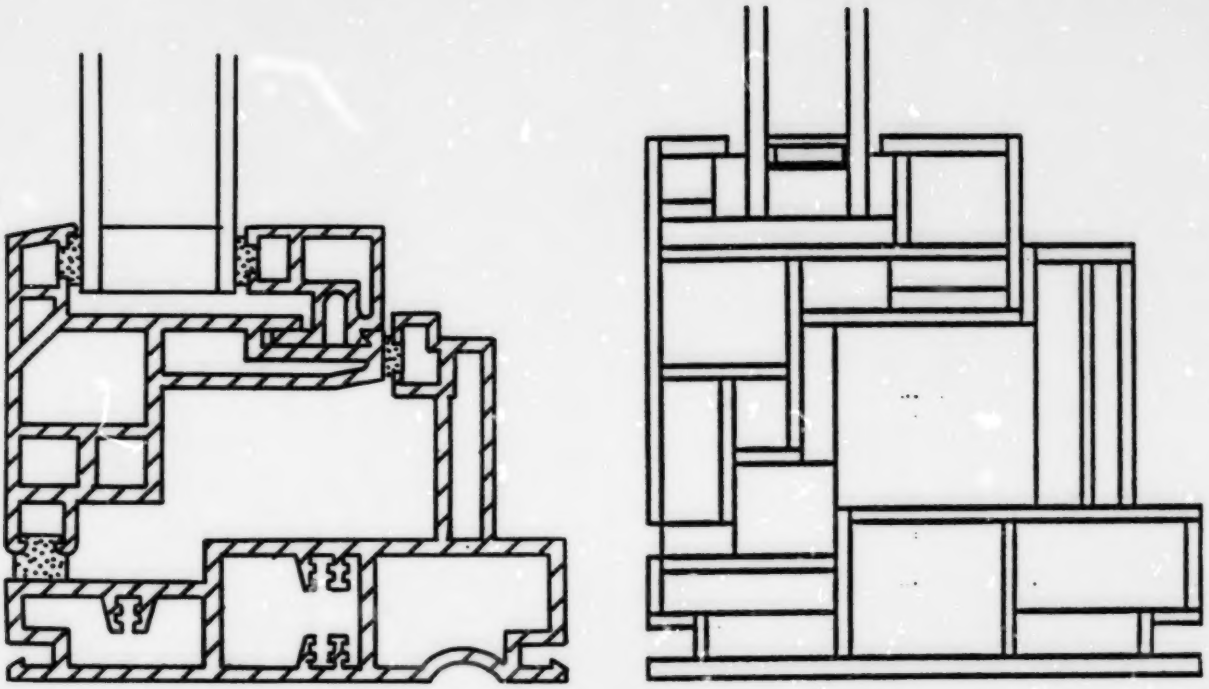
Aluminum Hinged Frame with 9mm Thermal Break - H3



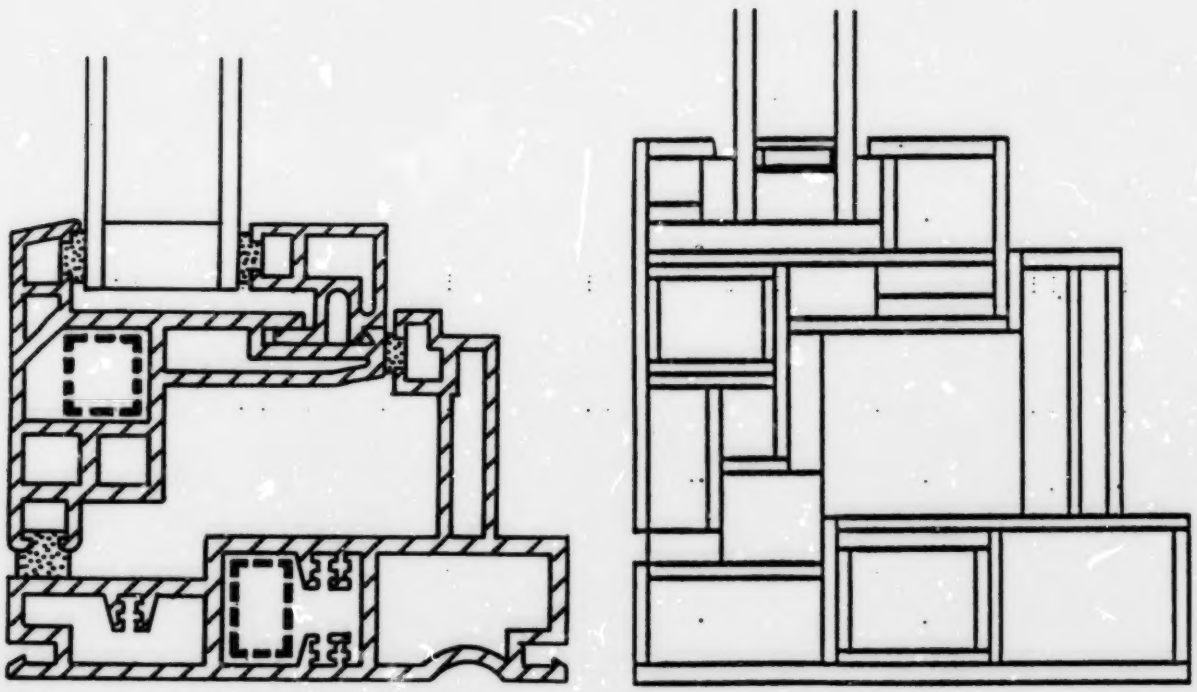
Aluminum Hinged Frame with 18mm Thermal Break - H4



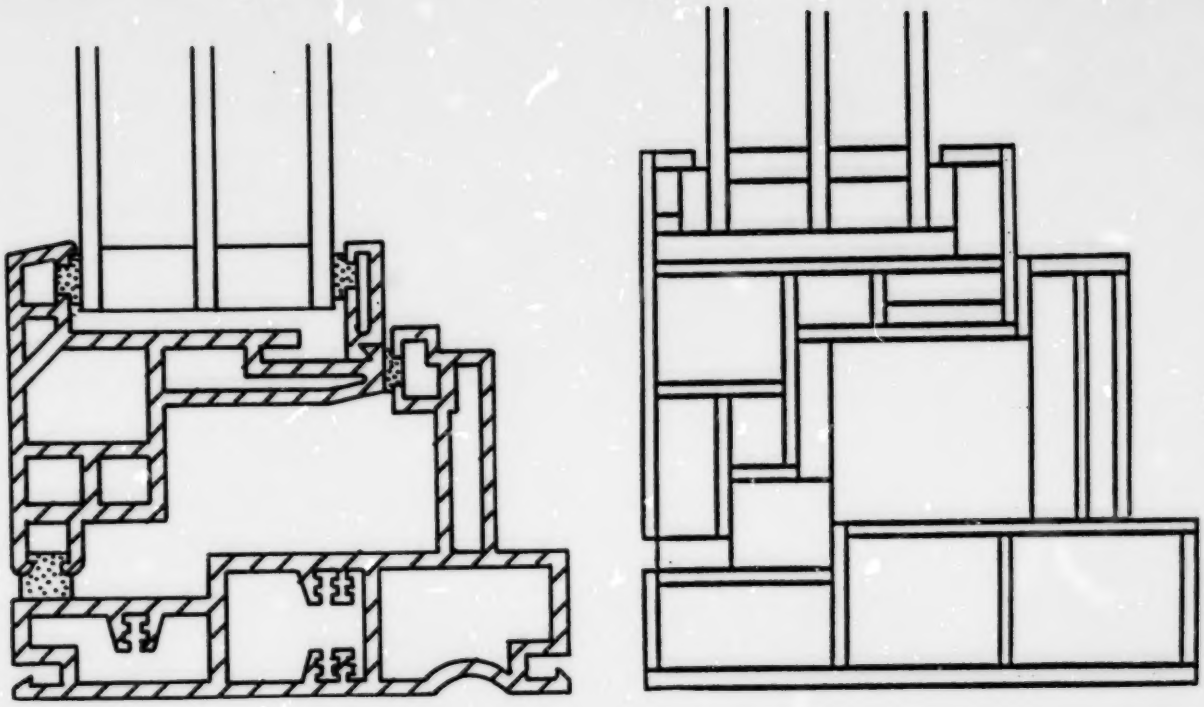
Fibreglass Hinged Frame - H5



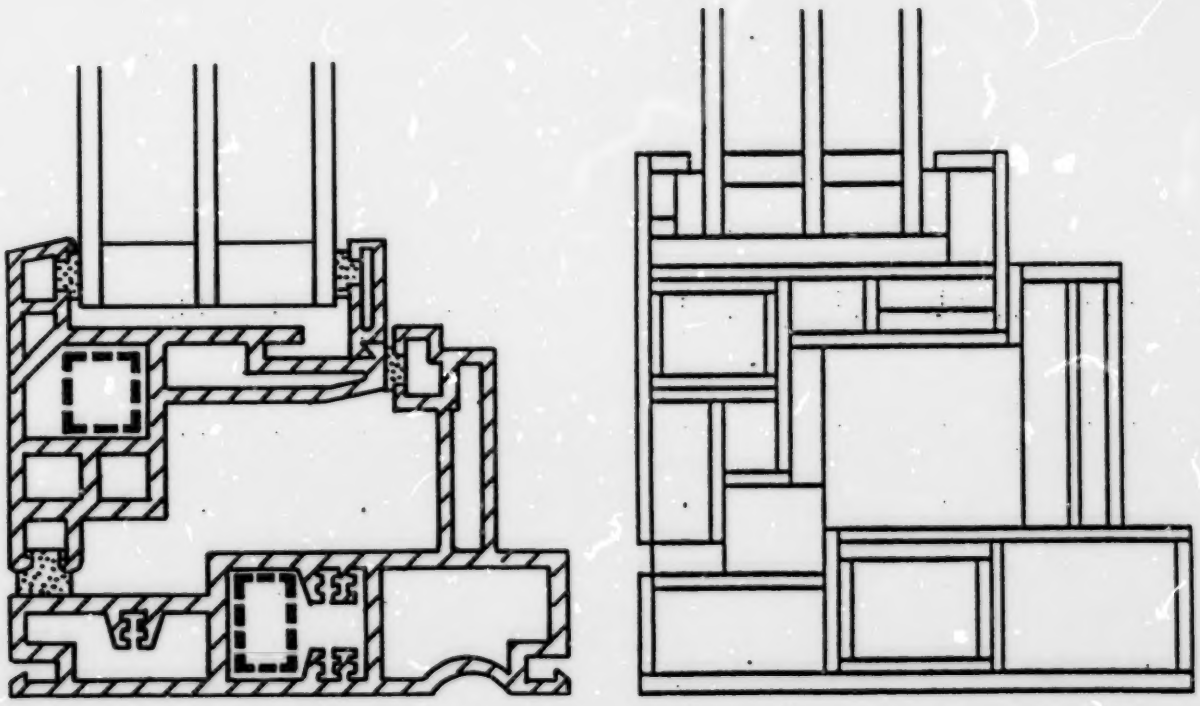
Vinyl Hinged Frame: Double-Glazed - H6



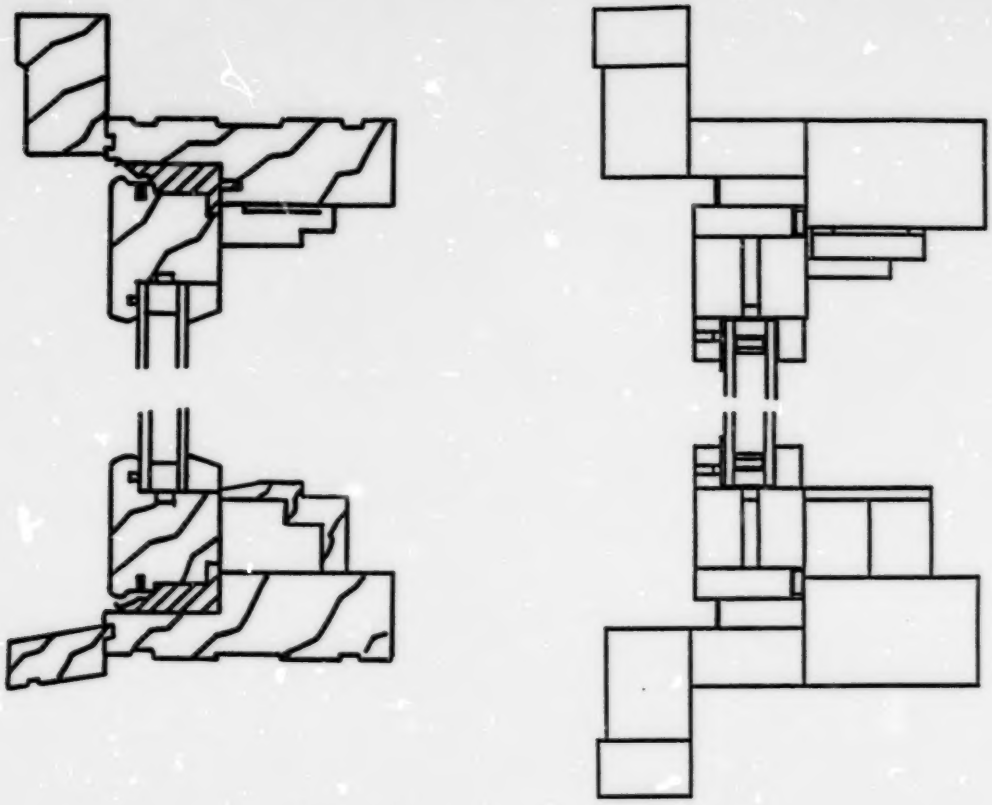
Reinforced Vinyl Hinged Frame: Double-Glazed - H8



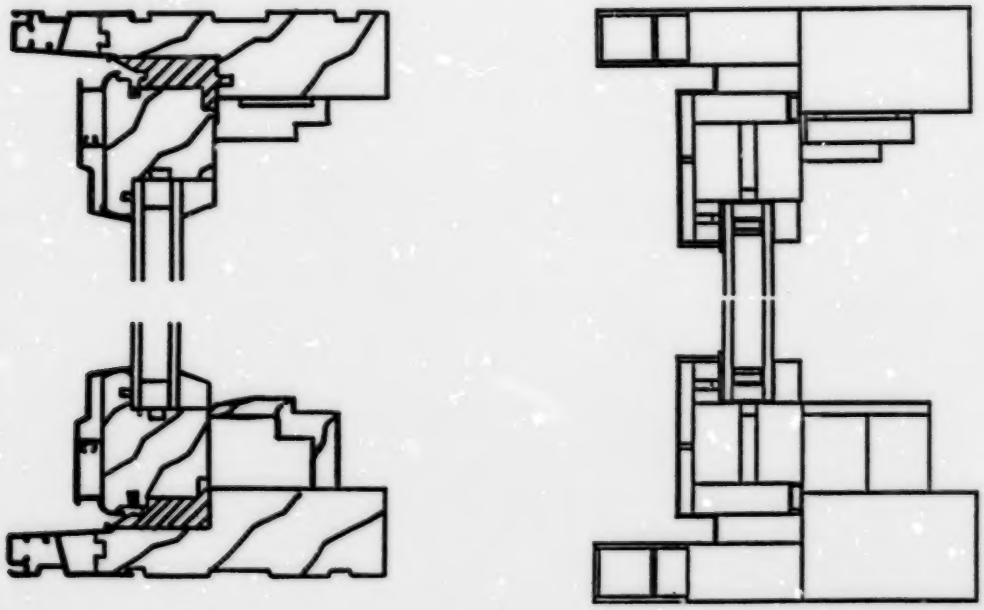
Vinyl Hinged Frame: Triple-Glazed - H7



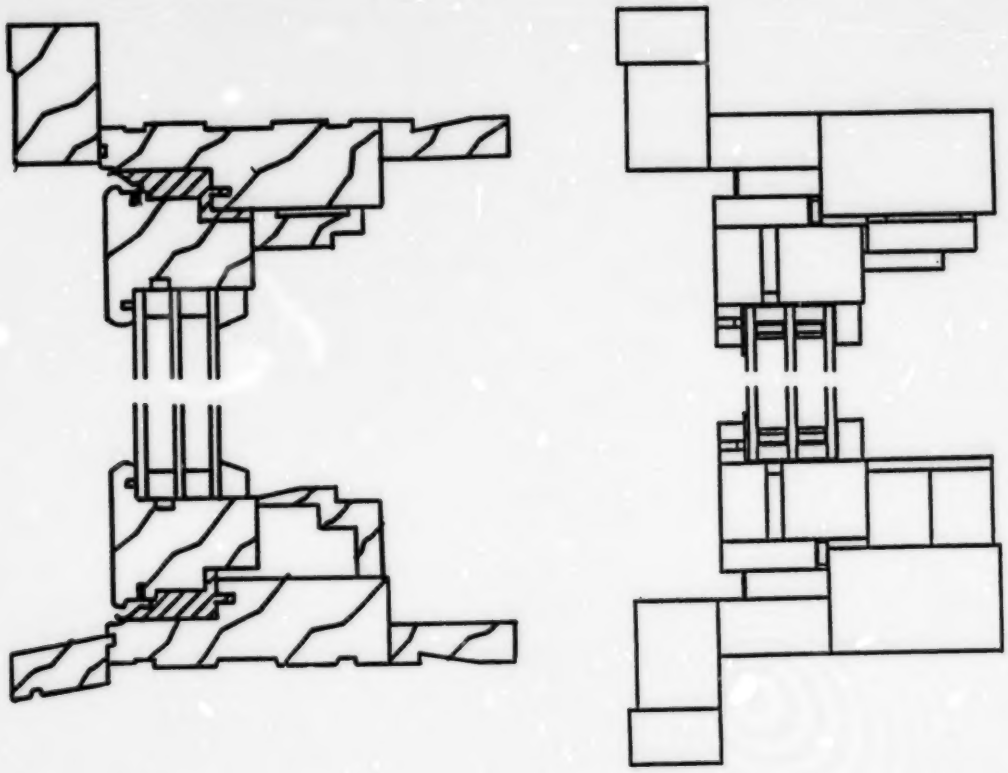
Reinforced Vinyl Hinged Frame: Triple-Glazed - H9



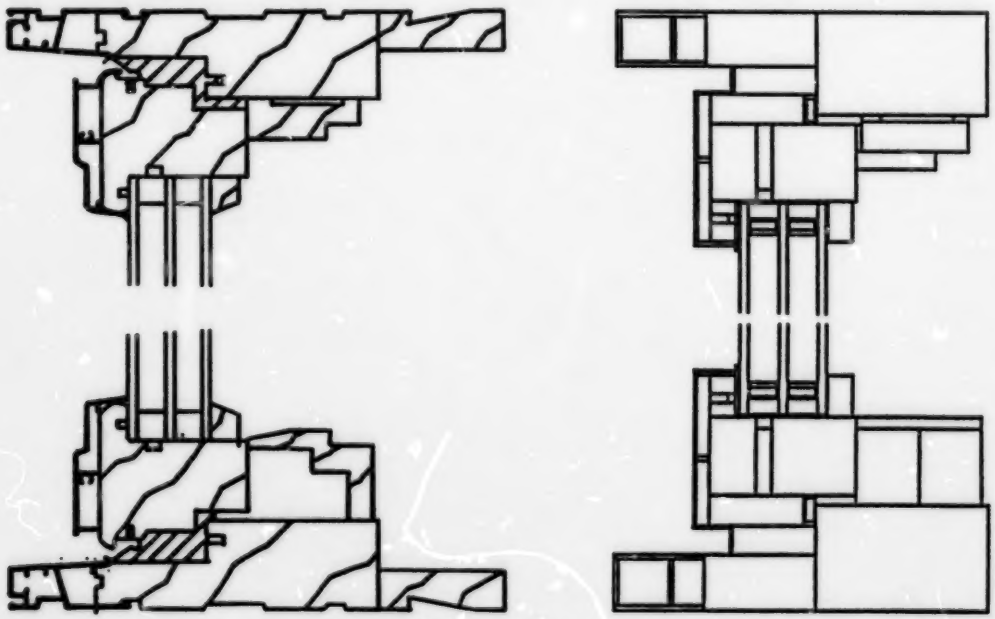
Wood Hinged Frame: Double-Glazed - H10



Aluminum-Clad Wood Hinged Frame: Double-Glazed - H12



Wood Hinged Frame: Triple-Glazed - H11

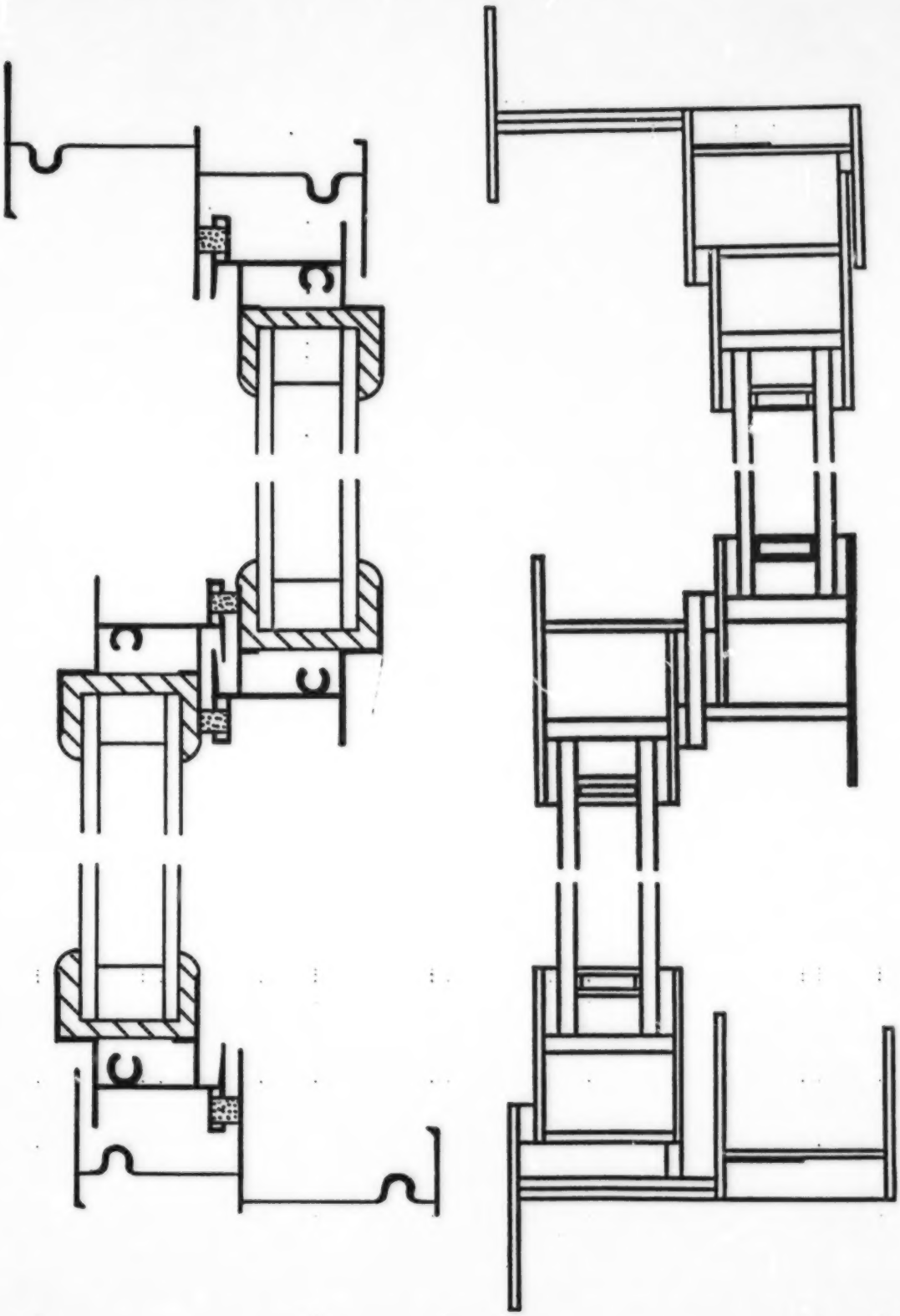


Aluminum-Clad Wood Hinged Frame: Triple-Glazed - H13

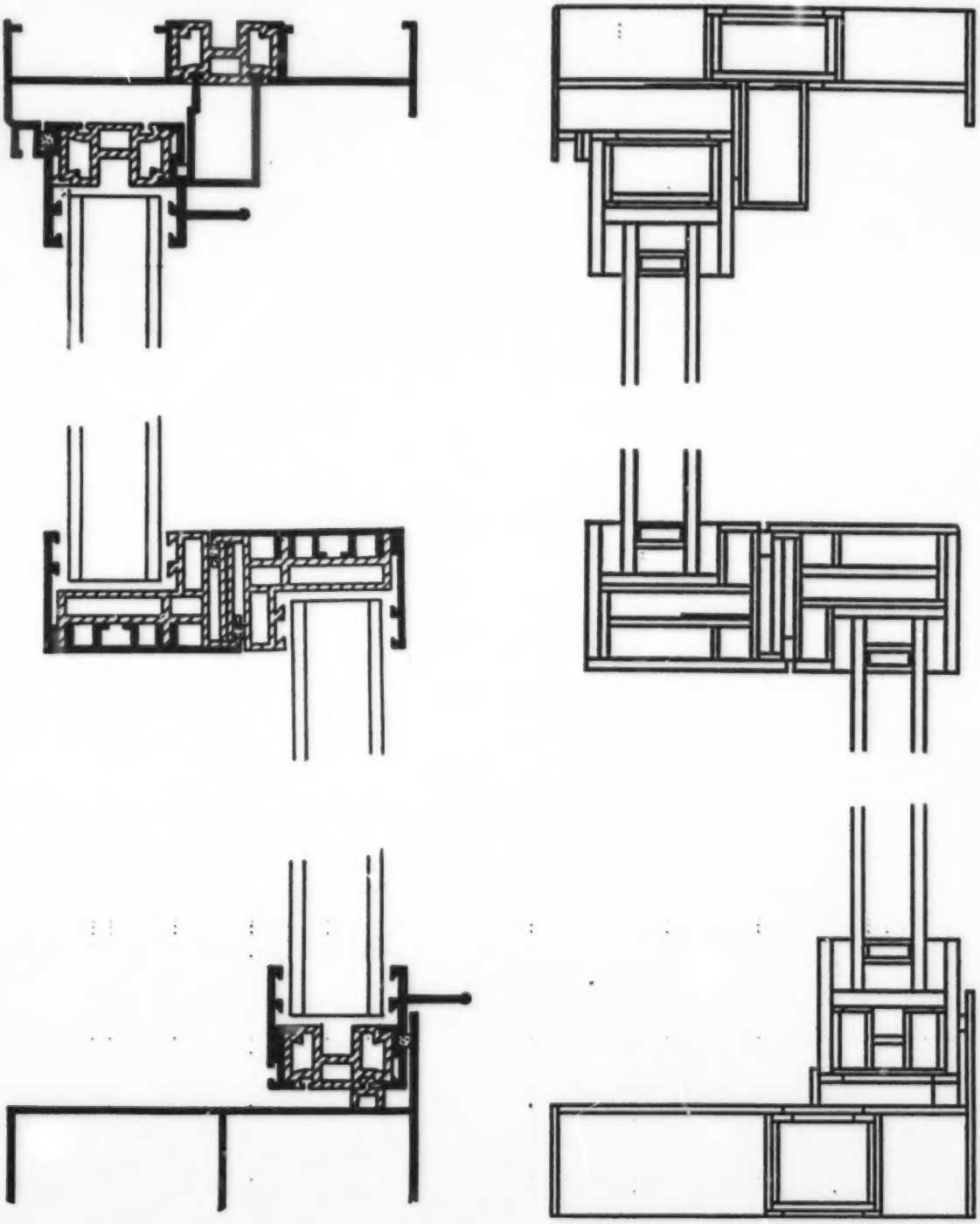
APPENDIX B.3: SLIDING WINDOW CROSS-SECTIONS

Notes:

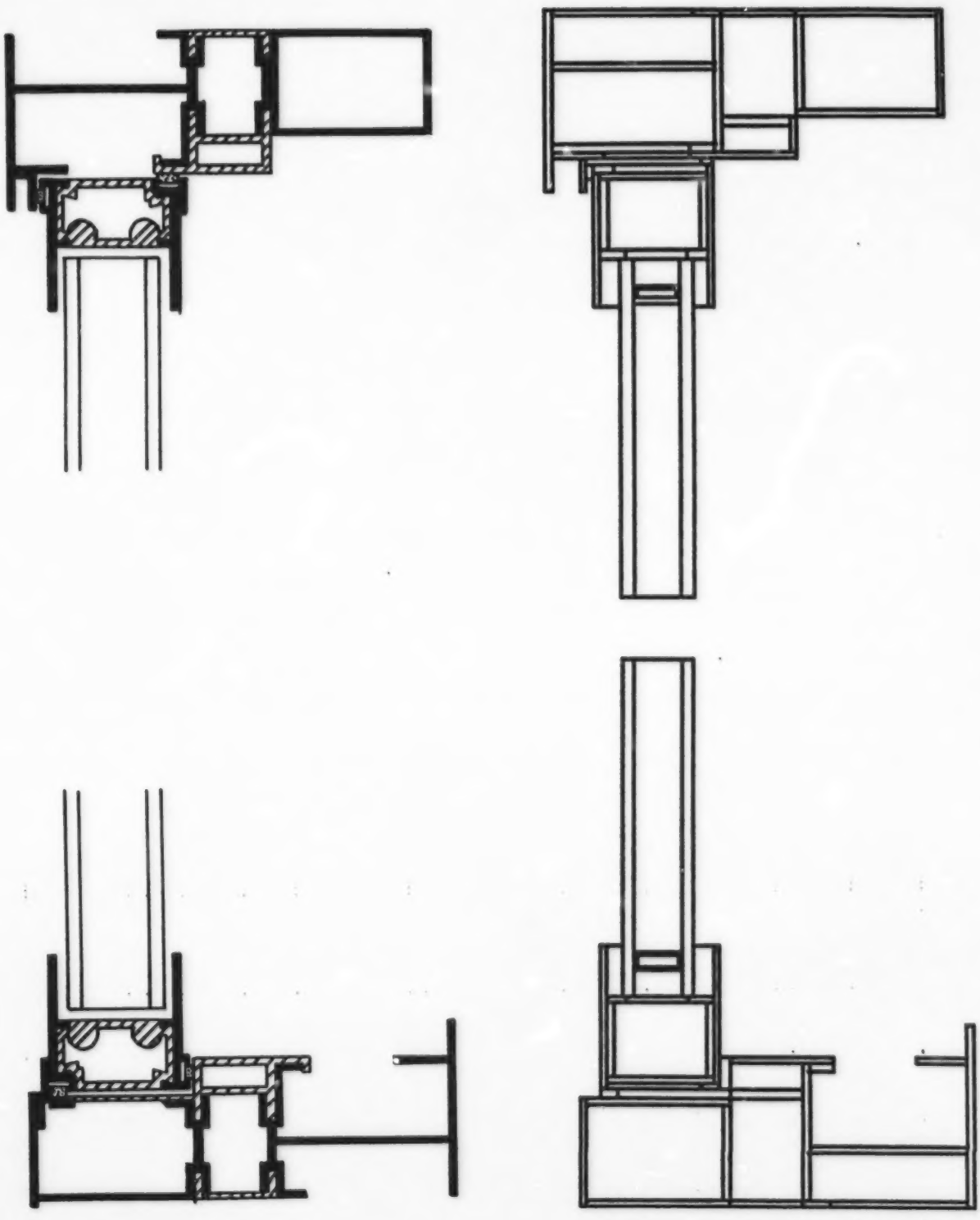
1) Actual Cross-Section on left, FRAME Program representation on right.
2) All units are shown as horizontal sliders.
3) Material Legend:



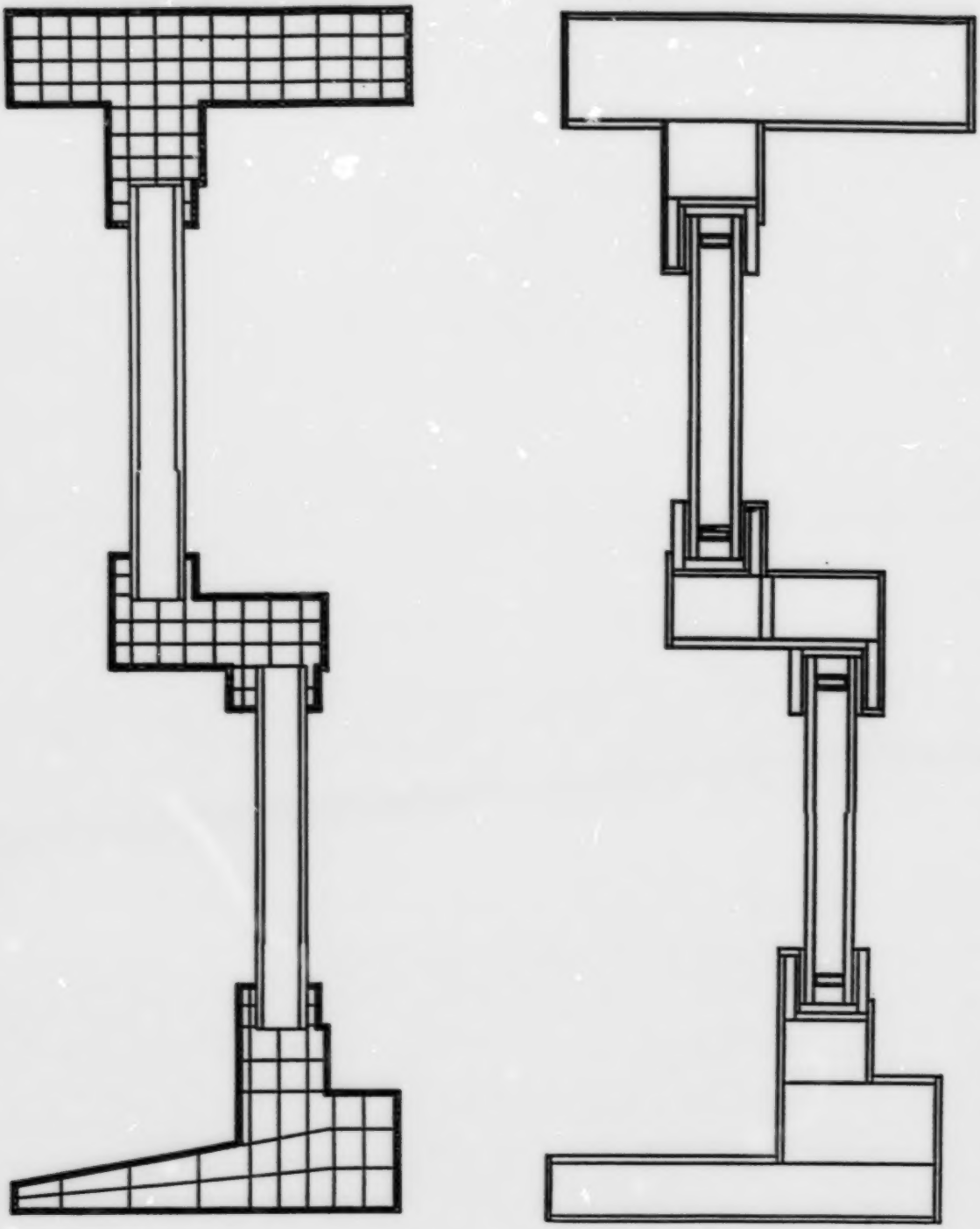
Aluminum Sliding Frame - S1



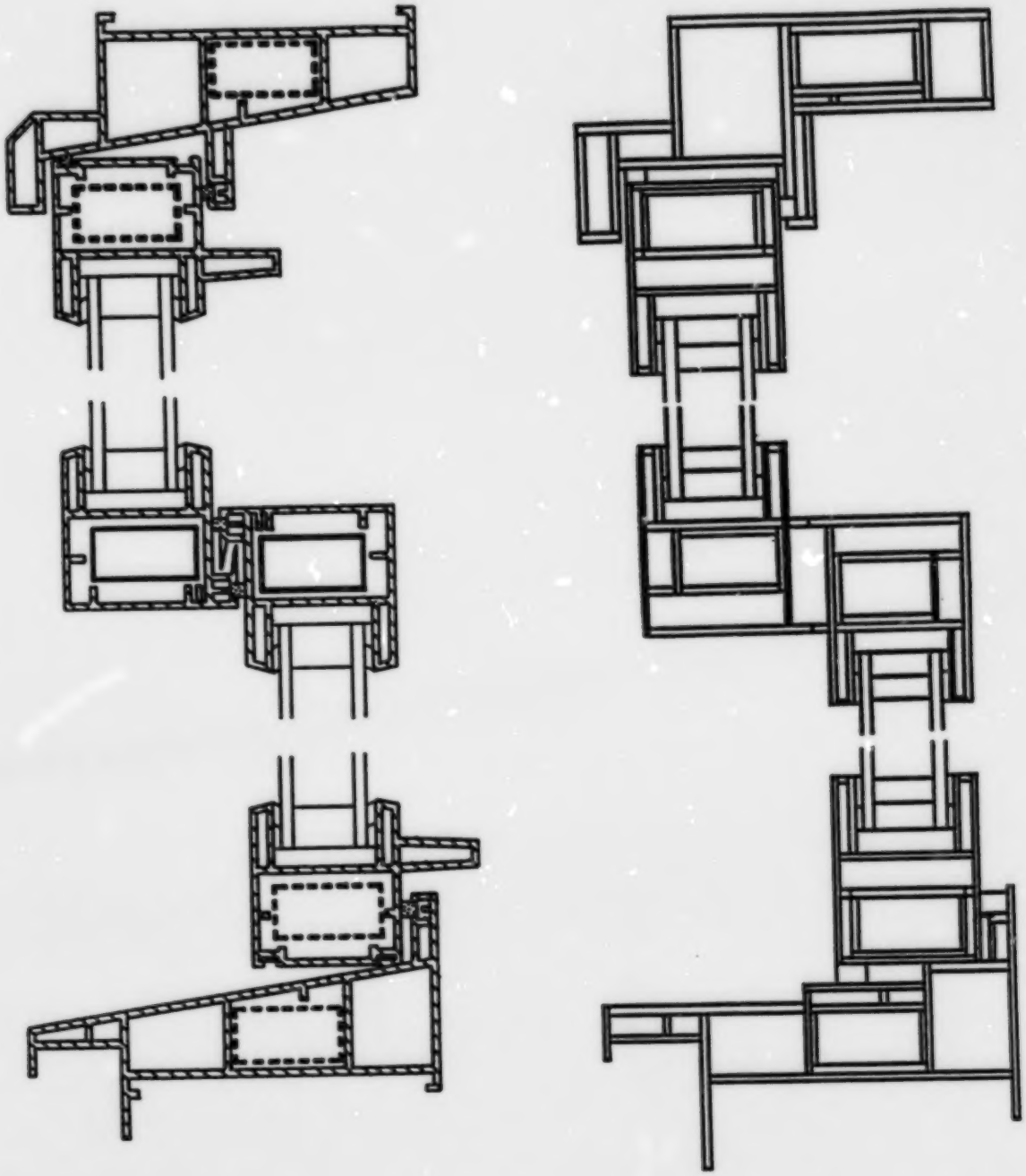
Aluminum Sliding Frame with 20mm Thermal Break (Horizontal Cross-Section) - S2



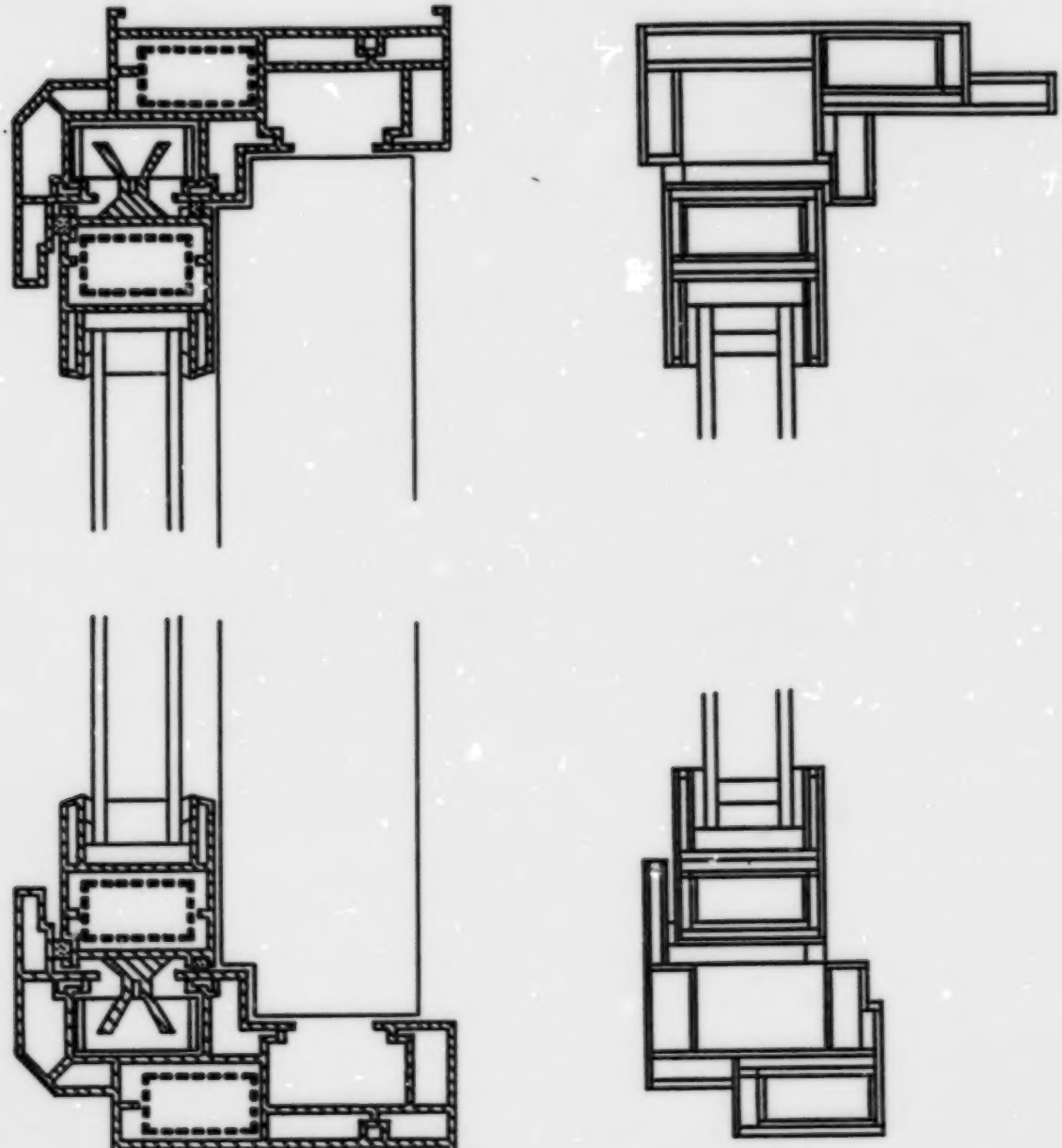
Aluminum Sliding Frame with 20mm Thermal Break (Vertical Cross-Section) - S2



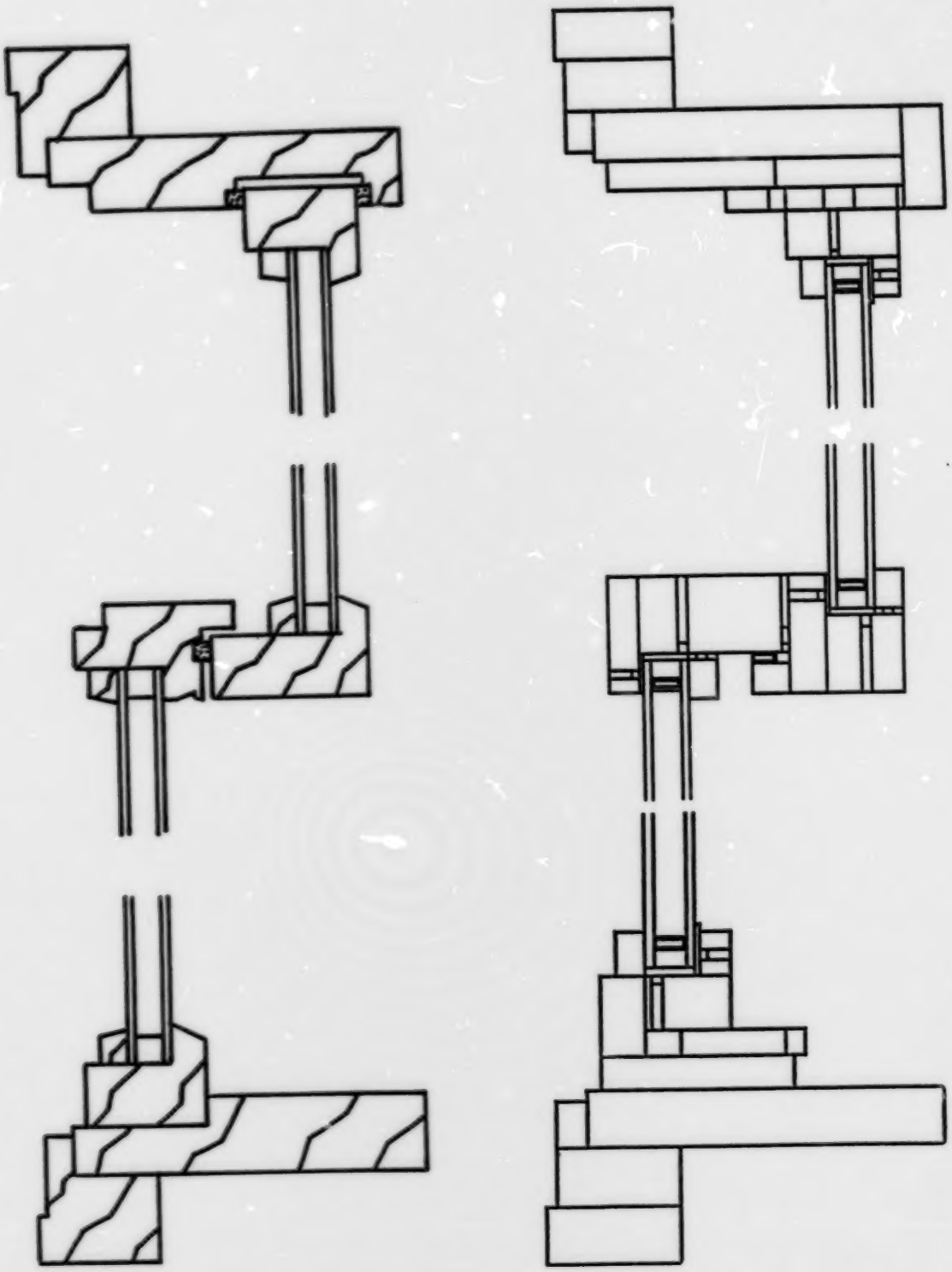
Fibreglass Sliding Frame - S3



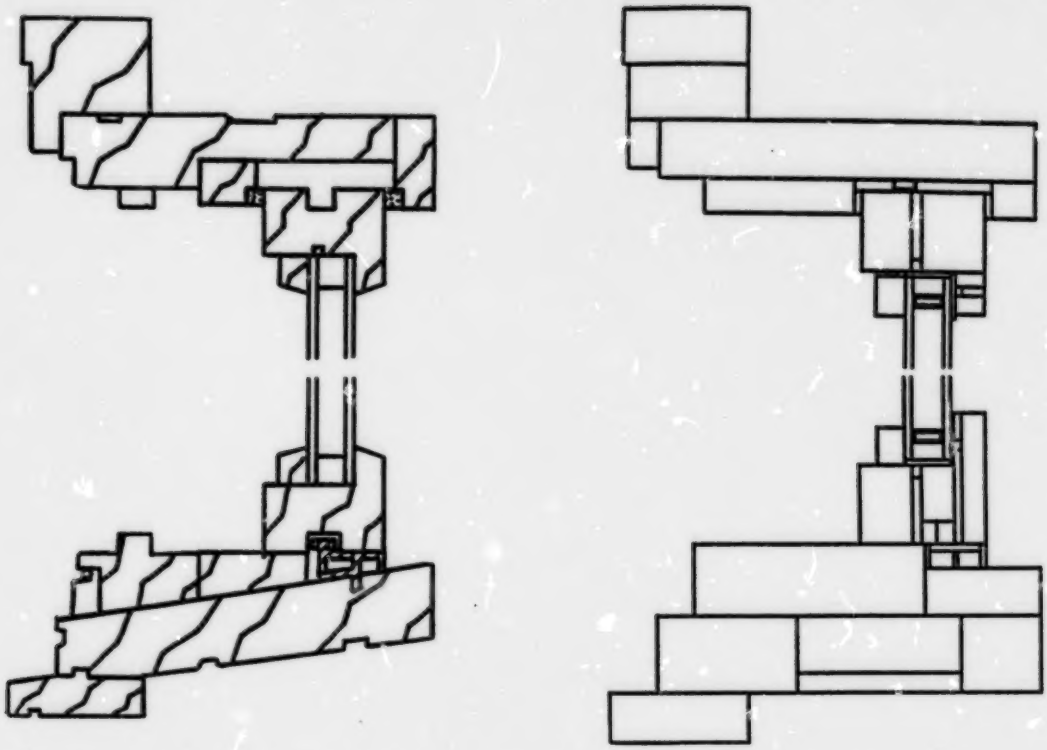
Vinyl Sliding Frame (with and without reinforcing) (Horizontal Cross-Section) - S4



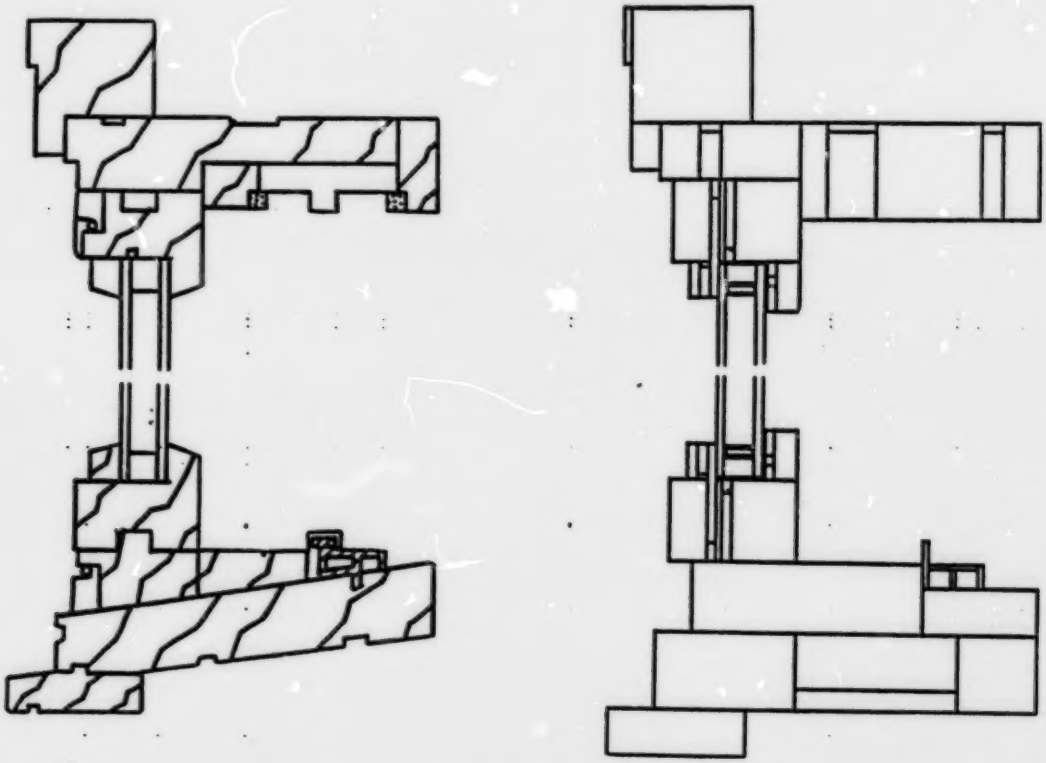
Vinyl Sliding Frame (with and without reinforcing) (Vertical Cross-Section) - S4



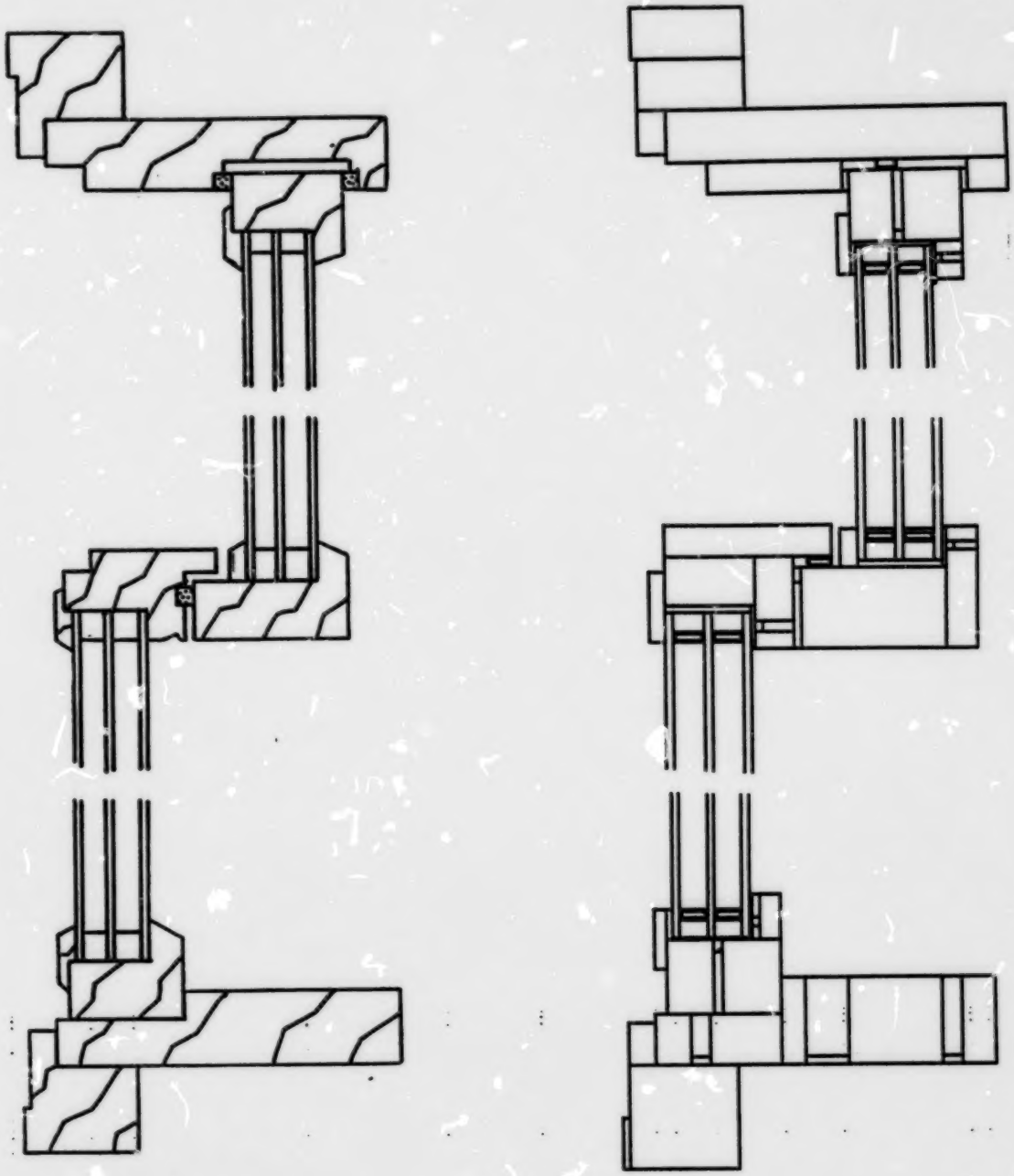
Double-Glazed Wood Sliding Frame (Horizontal Cross-Section) - S5



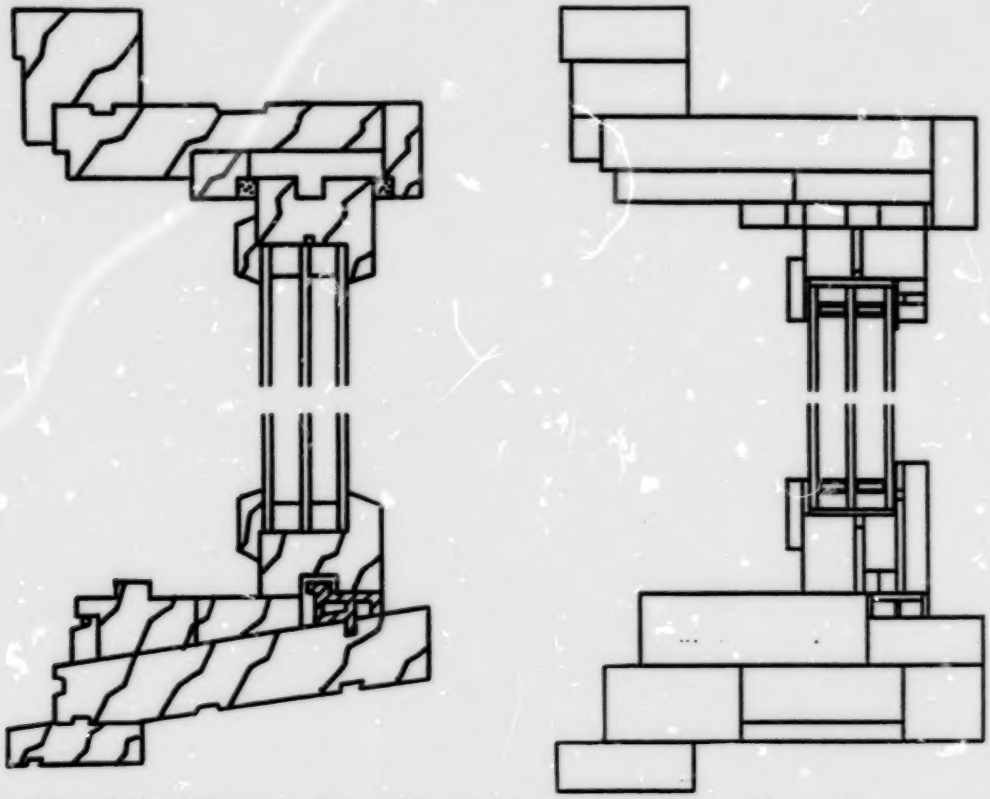
Double-Glazed Wood Sliding Frame (Vertical Cross-Section: 1) - S5



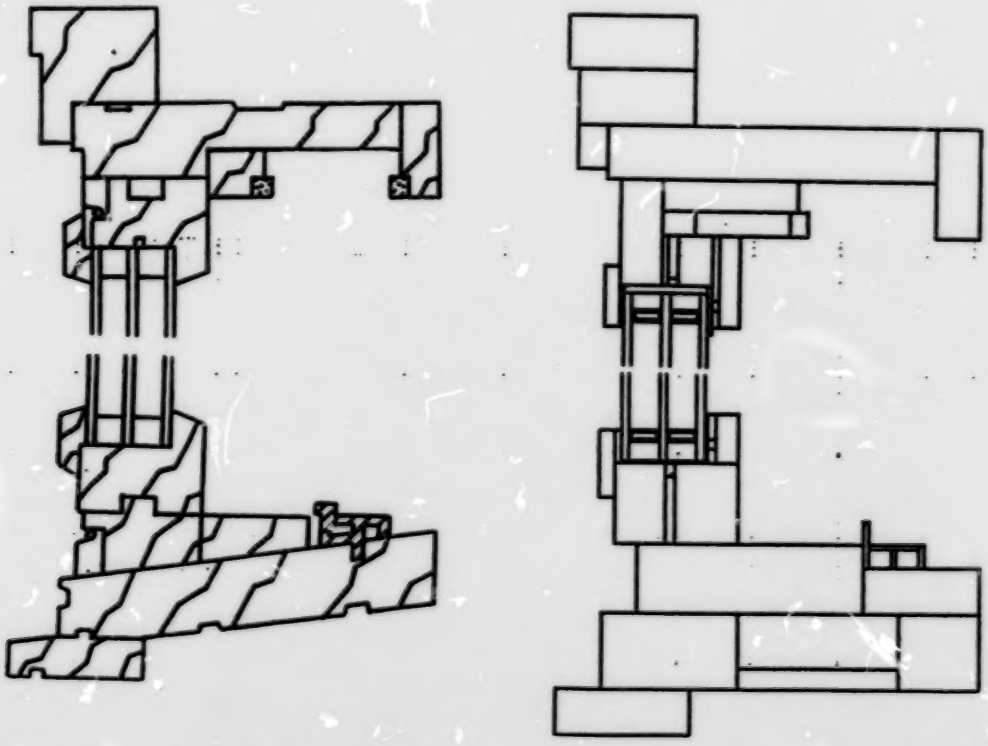
Double-Glazed Wood Sliding Frame (Vertical Cross-Section: 2) - S5



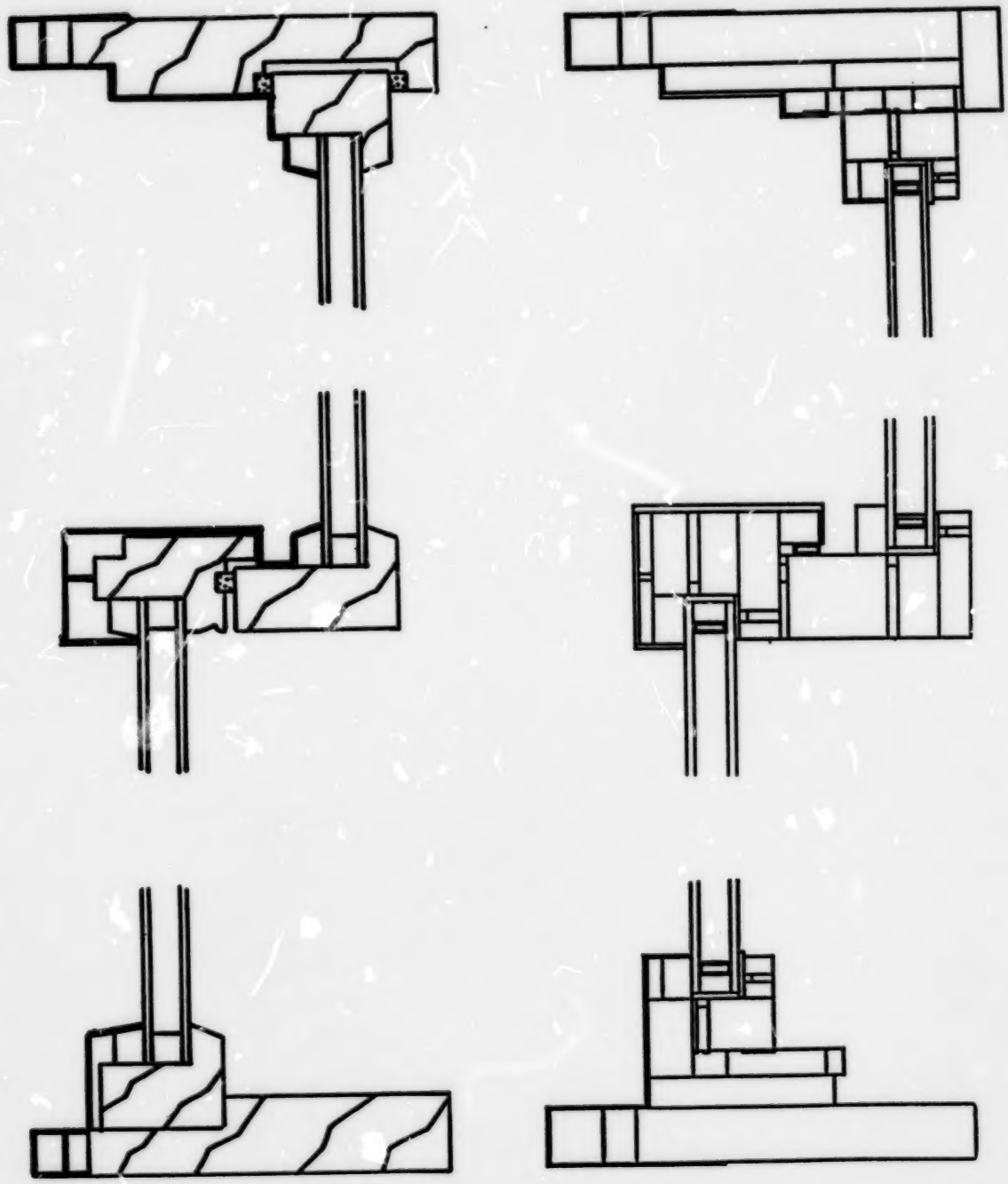
Triple-Glazed Wood Sliding Frame (Horizontal Cross-Section) - S6



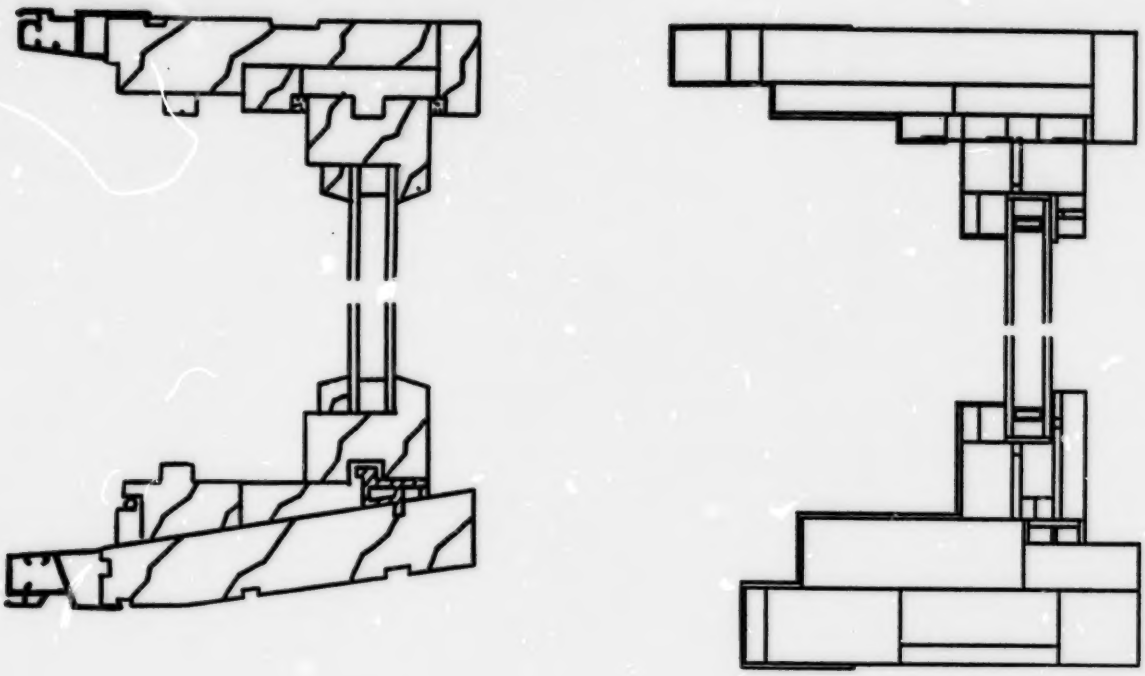
Triple-Glazed Wood Sliding Frame (Vertical Cross-Section: 1) - S6



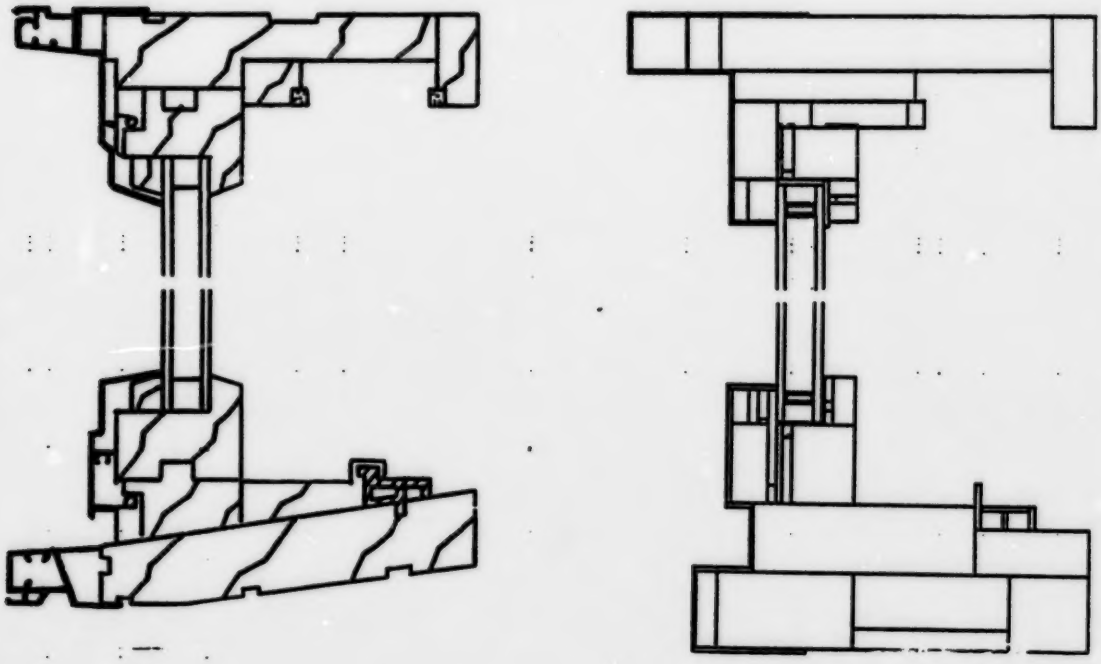
Triple-Glazed Wood Sliding Frame (Vertical Cross-Section: 2) - S6



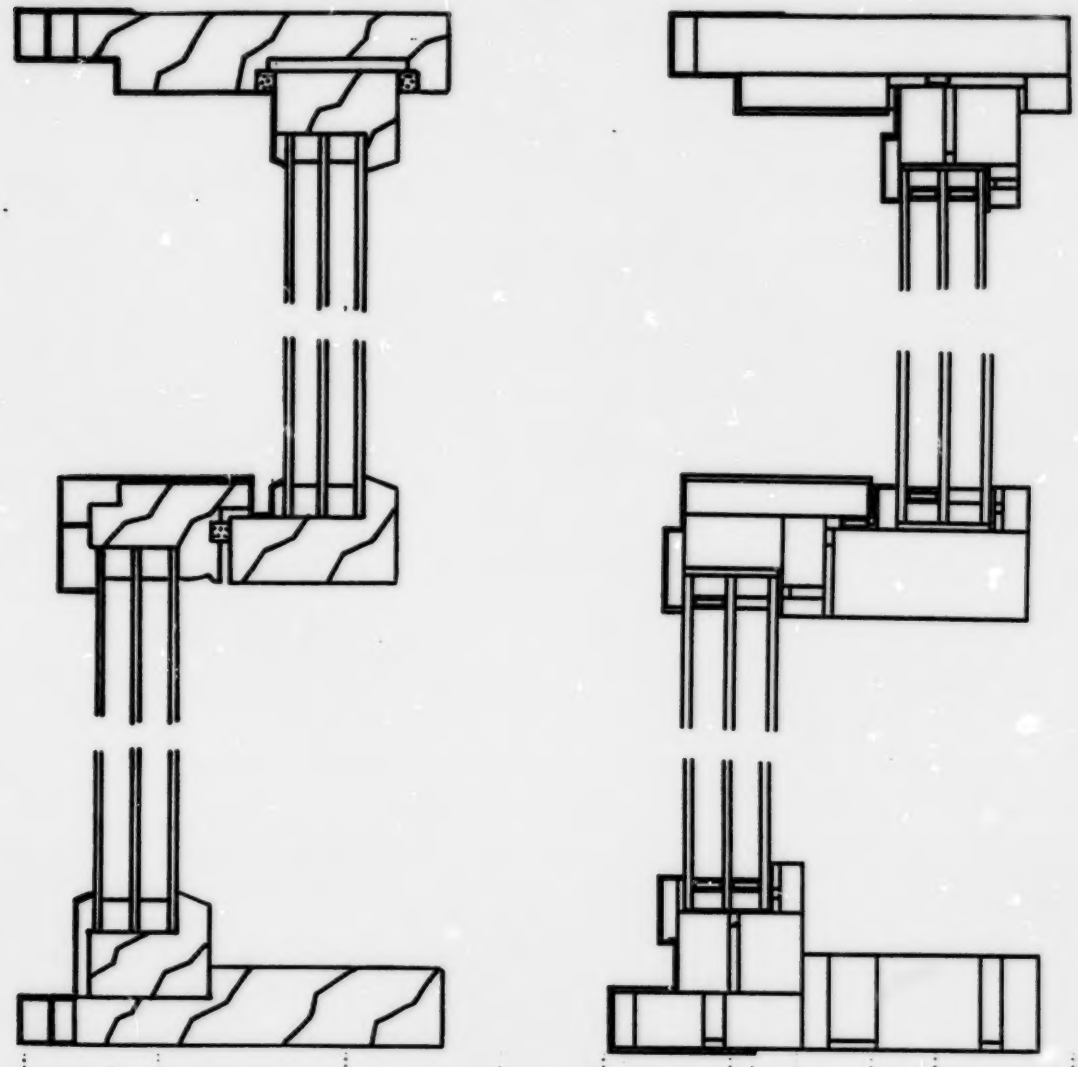
Double-Glazed Aluminum-Clad Wood Sliding Frame (Horizontal Cross-Section) - S7



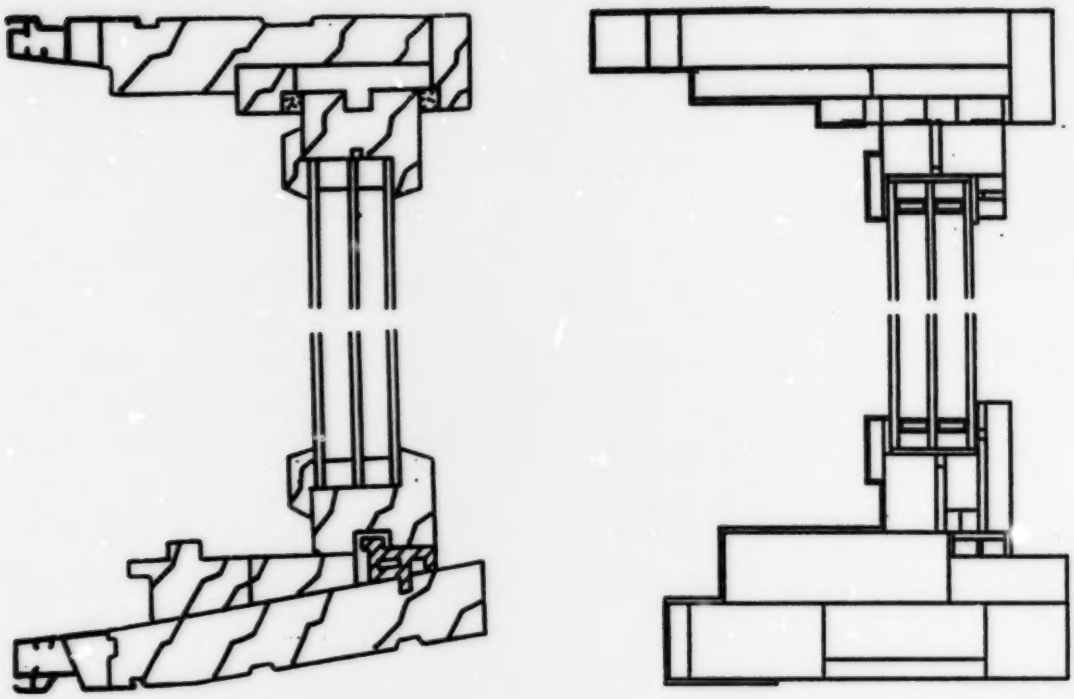
Double-Glazed Aluminum-Clad Wood Sliding Frame (Vertical Cross-Section: 1) - S7



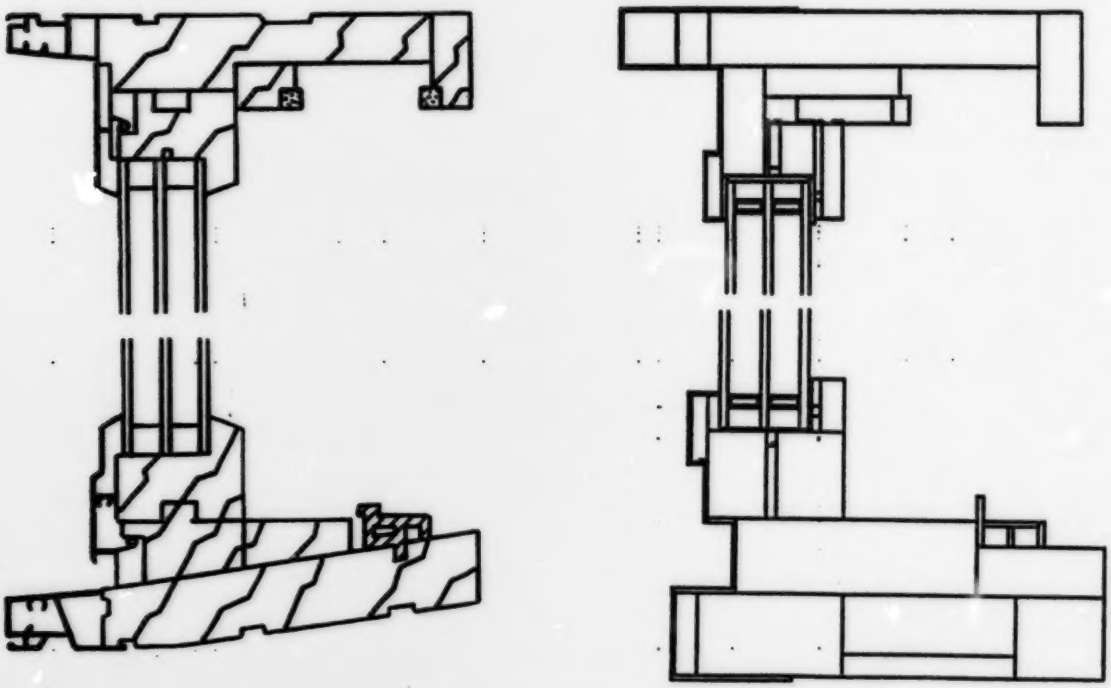
Double-Glazed Aluminum-Clad Wood Sliding Frame (Vertical Cross-Section: 2) - S7



Triple-Glazed Aluminum-Clad Wood Sliding Frame (Horizontal Cross-Section) - S8



Triple-Glazed Aluminum-Clad Wood Sliding Frame (Vertical Cross-Section: 1) - S8



Triple-Glazed Aluminum-Clad Wood Sliding Frame (Vertical Cross-Section: 2) - S8

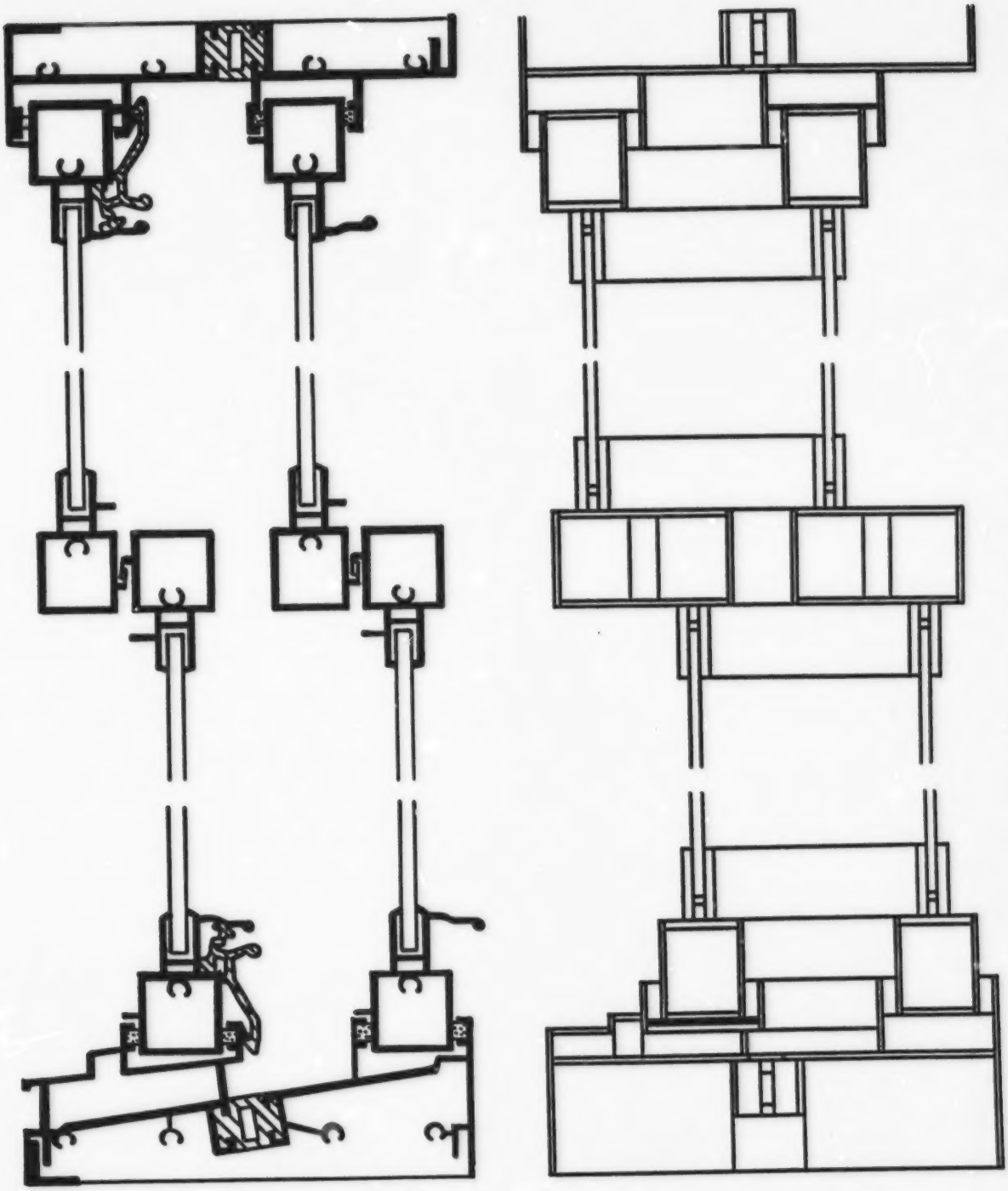
APPENDIX B.4: Semi-sashless SLIDING CROSS-SECTIONS

Notes:

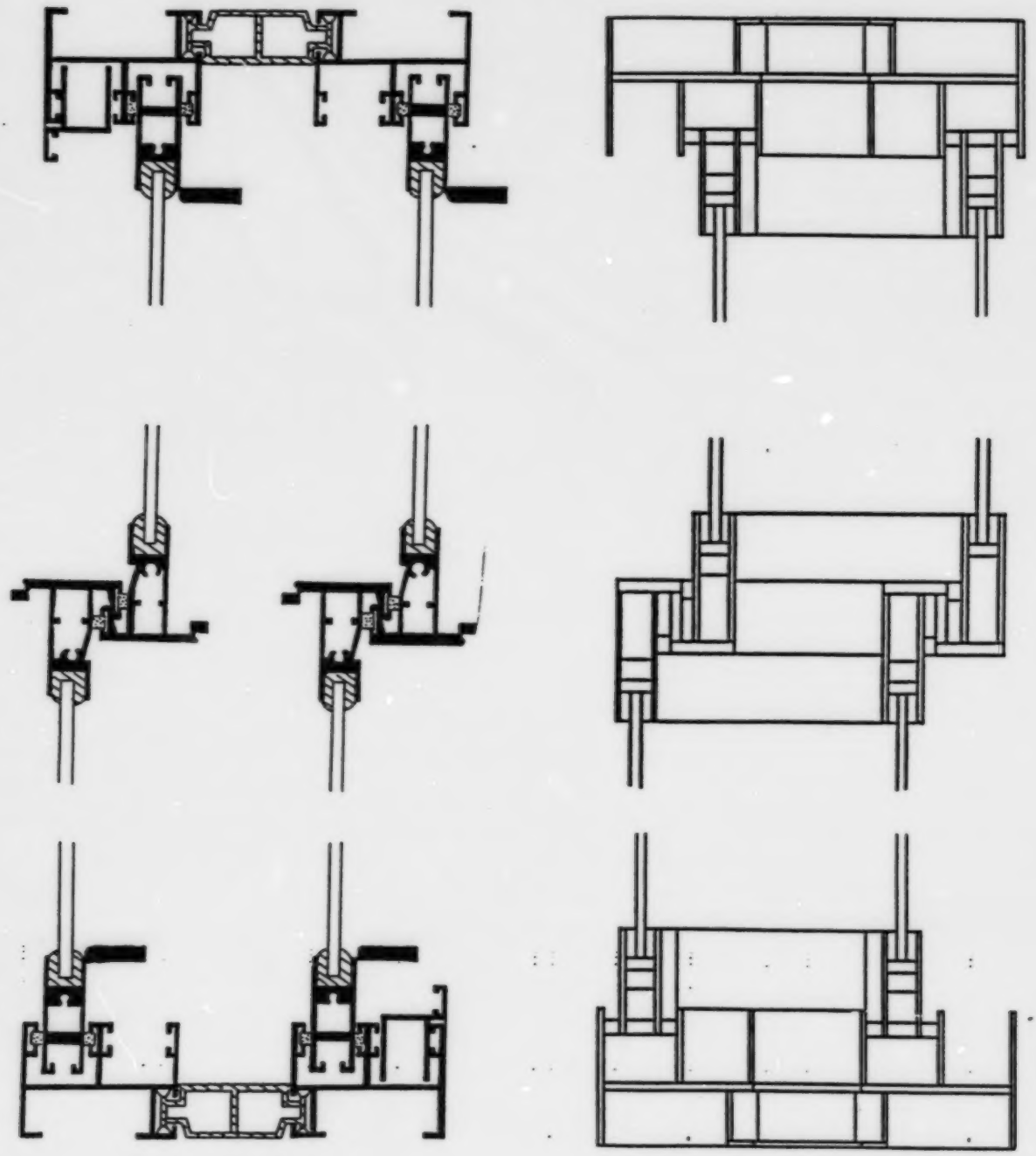
1) Actual Cross-Section on left, FRAME Program representation on right.

3) All units are shown as horizontal sliders.

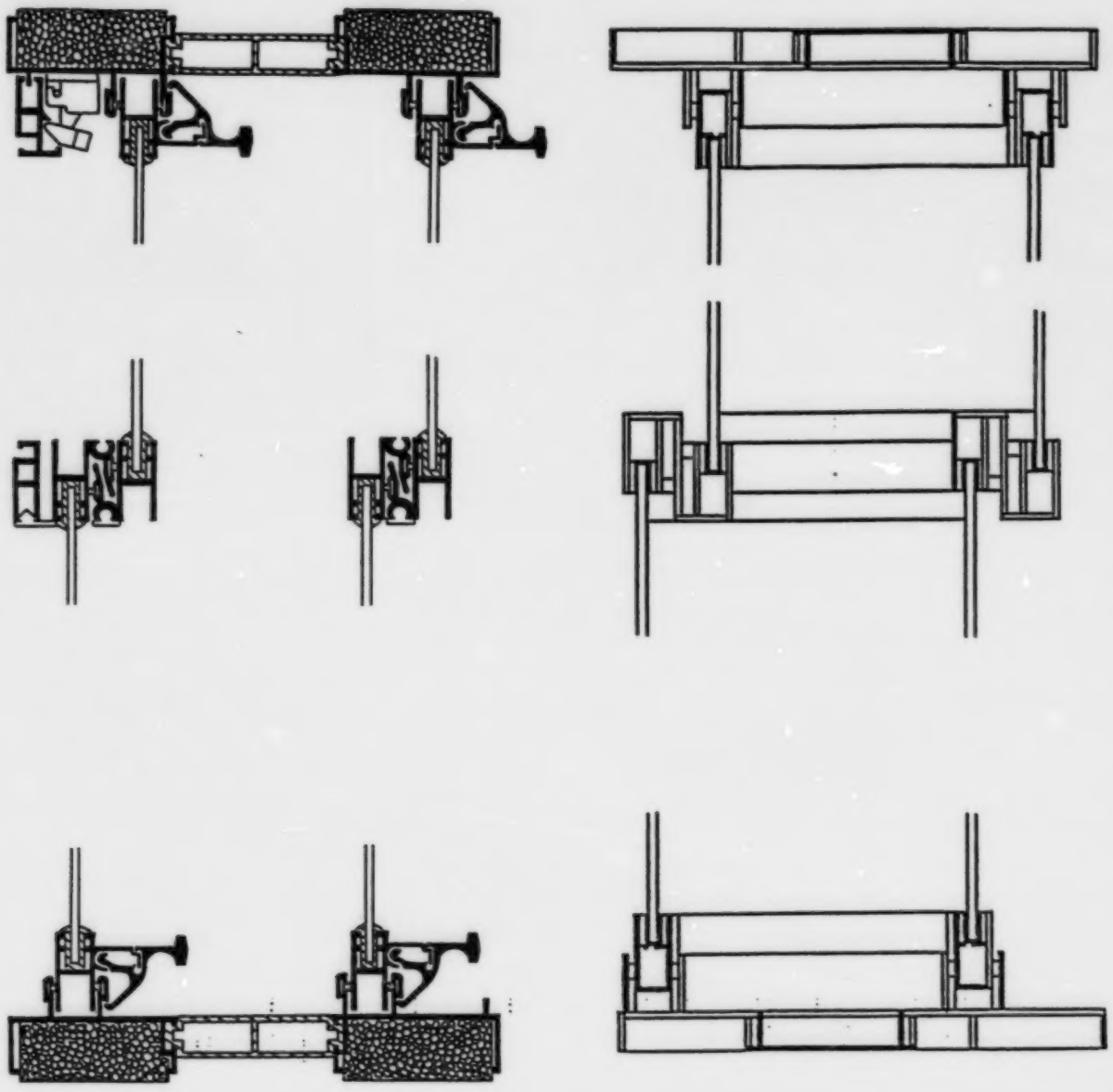
4) Material Legend:



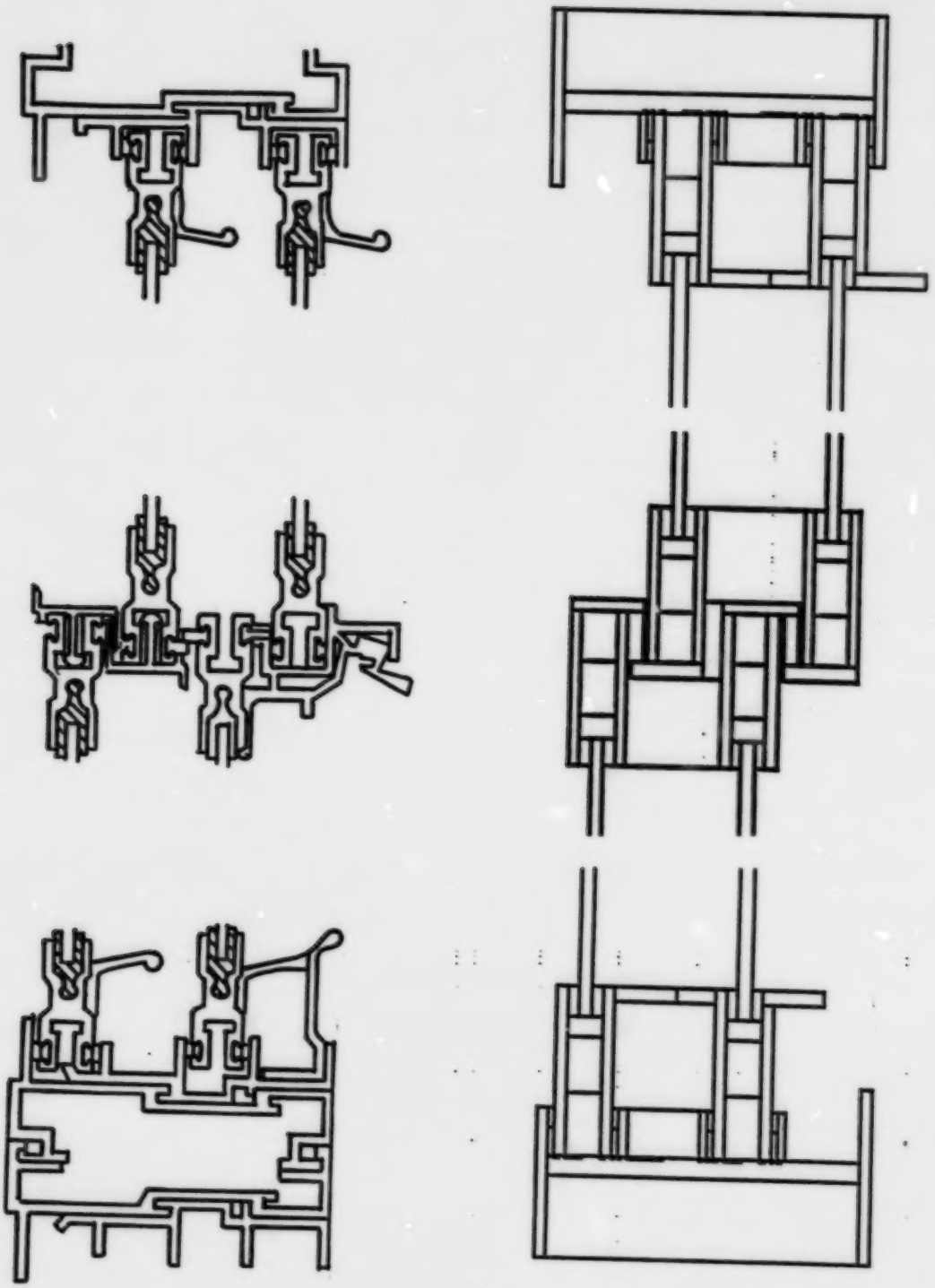
Aluminum Sashless Sliding Frame with 10mm Thermal Break (Horizontal Cross-Section)- S9
(same cross-section used for Aluminum Sashless Sliding Frame with no Thermal Break)



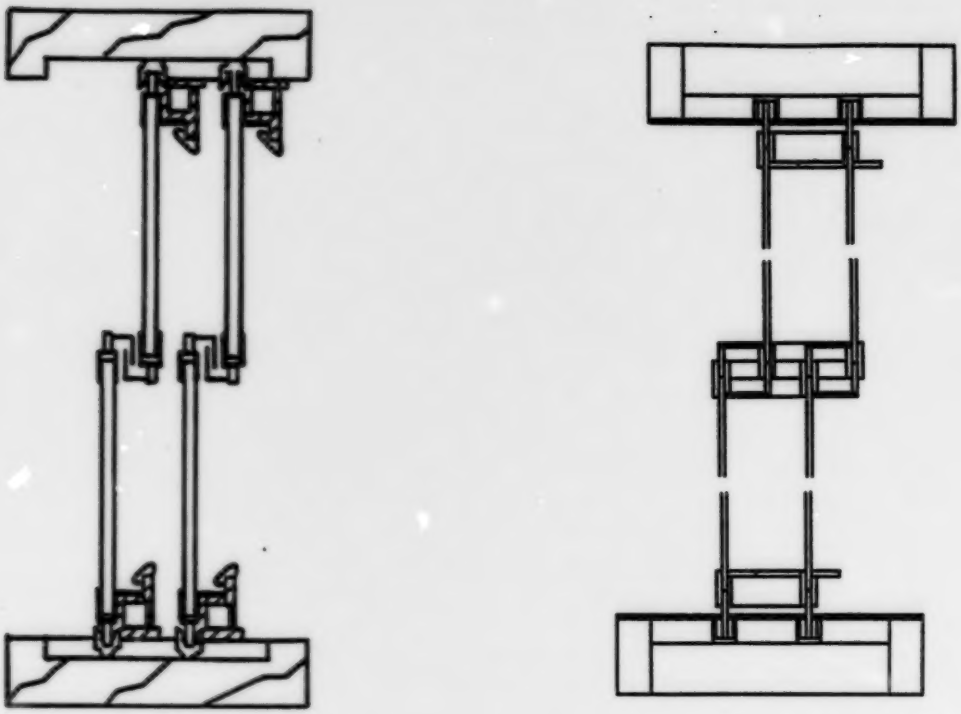
Aluminum Sashless Sliding Frame with 35mm Thermal Break (Horizontal Cross-Section)-S10



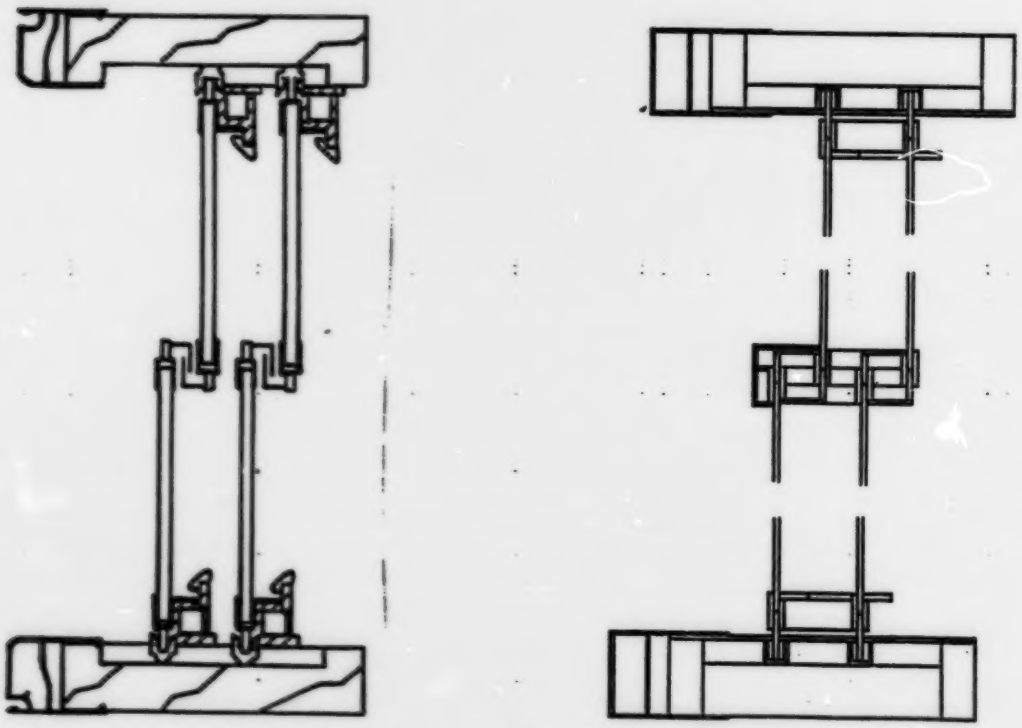
Aluminum Sashless Sliding Frame with 50mm Thermal Break (Horizontal Cross-Section)-S11



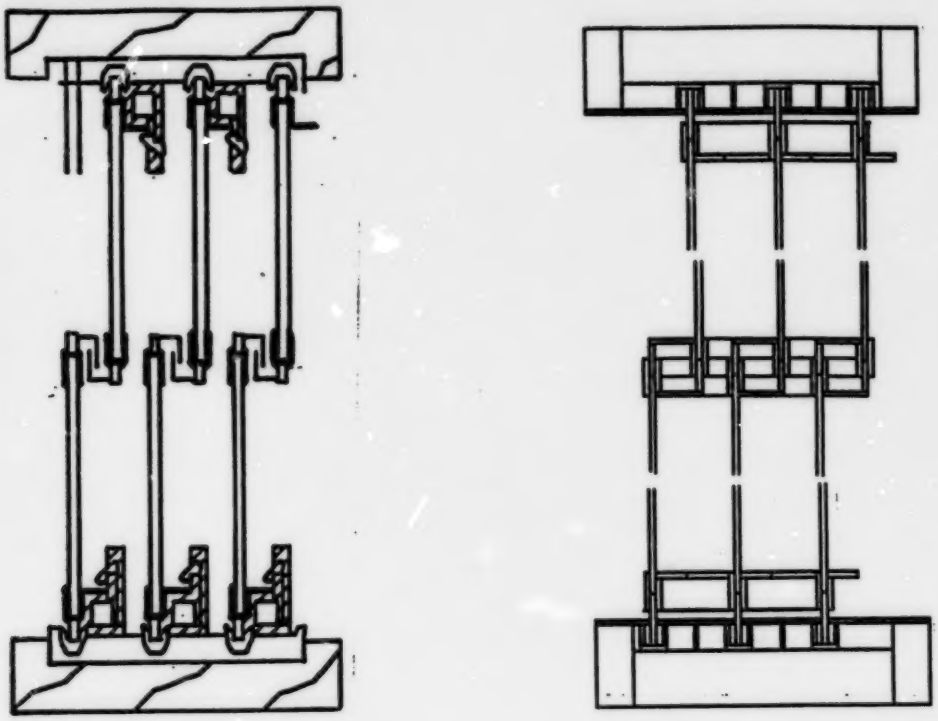
Fibreglass Sashless Sliding Frame (Horizontal Cross-Section) - S12



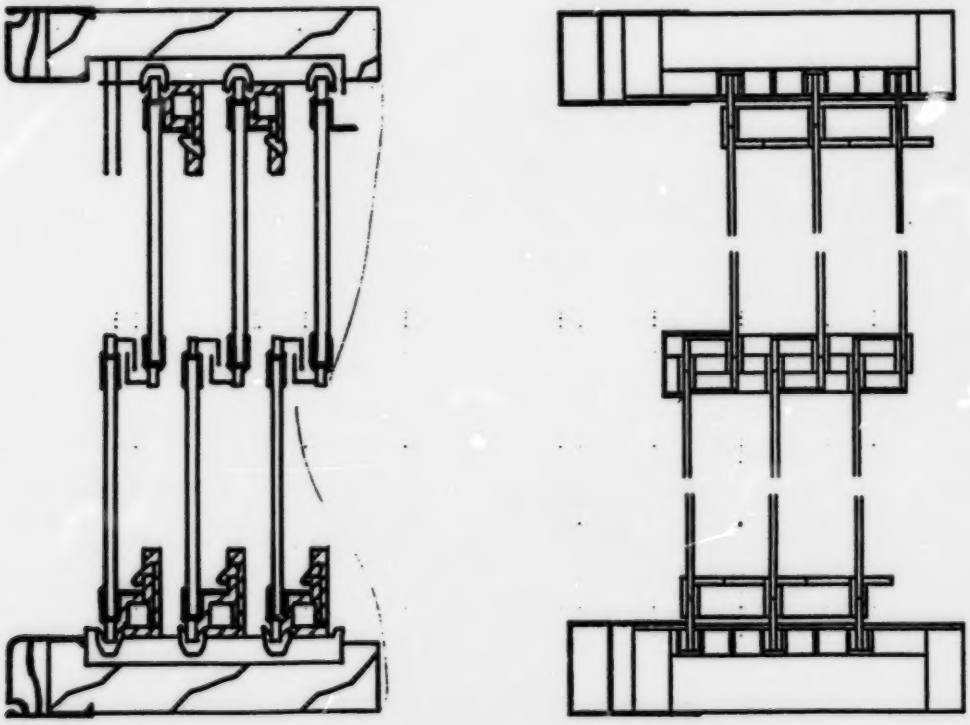
Double-Glazed Wood Sashless Sliding Frame (Horizontal Cross-Section) - S13



Double-Glazed Aluminum-Clad Wood Sashless Sliding Frame (Horizontal Cross-Section)-S15



Triple-Glazed Wood Sashless Sliding Frame (Horizontal Cross-Section) - S14



Triple-Glazed Aluminum-Clad Wood Sashless Sliding Frame (Horizontal Cross-Section)-S16

APPENDIX C
TOTAL WINDOW U-VALUE and SHGC CALCULATION SHEET

STEP 1 WINDOW U-VALUE

I Centre of Glass U-value from Table 5

Centre of Glass U-value _____

II Edge of Glass U-value Constants from Table 6

A = _____, B = _____, C = _____

$U_{eg} = A + B * U_{cg} + C * U_{cg}^2$ = _____

III Frame U-value from Tables 8 through 11

Metal Spacer _____

Insulating Spacer _____

Glass Spacer $0.50 * U_{metal} + 0.50 * U_{insul}$ = _____

Metal + Insul. Spacer $0.15 * U_{metal} + 0.85 * U_{insul}$ = _____

IV Component Fractions

Frame Height and Window Width and Height [mm]

Window Width, W = _____, Height, H = _____

Frame Height = _____, from Tables 8 through 11

Fraction Frame

Picture and Hinged Windows

$F_{fr} = [(W * H) - (W - 2 * H_{fr}) * (H - 2 * H_{fr})] / (W * H)$ _____

Vertical Sliding Windows

$F_{fr} = [(W * (H/2)) - (W - 2 * H_{fr}) * ((H/2) - 2 * H_{fr})] / (W * (H/2))$ _____

Horizontal Sliding Windows

$F_{fr} = [((W/2) * H) - ((W/2) - 2 * H_{fr}) * (H - 2 * H_{fr})] / ((W/2) * H)$ _____

Fraction Centre of Glass

Picture and Hinged Windows

$F_{cg} = [(W - 2 * H_{fr} - 127) * (H - 2 * H_{fr} - 127)] / (W * H)$ _____

Vertical Sliding Windows

$F_{cg} = [(W - 2 * H_{fr} - 127) * ((H/2) - 2 * H_{fr} - 127)] / (W * (H/2))$ _____

Horizontal Sliding Windows

$F_{cg} = [((W/2) - 2 * H_{fr} - 127) * (H - 2 * H_{fr} - 127)] / ((W/2) * H)$ _____

Fraction Edge of Glass

$F_{eg} = 1 - F_{cg} - F_{fr}$ _____

V Window U-value

$U_{total} = U_{cg} * F_{cg} + U_{eg} * F_{eg} + U_{fr} * F_{fr}$ _____

STEP 2 SHGC CALCULATION

I Centre of Glass SHGC from Table 14

$SHGC_{cg}$ _____

II Frame SHGC

$SHGC_{fr} = 0.015 * a_{fr} * U_{fr}$ = _____

III Window SHGC

$SHGC_{total} = SHGC_{cg} * F_{cg} + SHGC_{eg} * F_{eg} + SHGC_{fr} * F_{fr}$ = _____